DOCUMENT RESUME

ED 423 147 SE 061 792

AUTHOR	Discenna, Jennifer
TITLE	A Study of Knowledge Structure in Physics.
PUB DATE	1998-04-00
NOTE	47p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Diego, CA, April 13-17, 1998).
PUB TYPE	Reports - Research (143) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC02 Plus Postage.
DESCRIPTORS	*Cognitive Processes; Concept Formation; Elementary Secondary Education; Higher Education; *Knowledge Representation; Learning Theories; Models; *Physics; Problem Solving; Science Education

ABSTRACT

This research study focused on the knowledge structure of the domain of physics by describing the knowledge of experts, intermediates, and novices. In order to investigate these representations, a reiterative categorization task was employed using novice, intermediate, and expert subjects (N=27). The categories were classified as theory-, model-, or mathematical model-based categories, and proportions of these categories were compared by level of expertise in order to compare subjects' categorization with the competing models. Results support a combined representation of physics knowledge based on both theories and models with the novice representation being a hierarchy of models. The highest level for both intermediates and experts was the theory used to solve the problem. Model-based categories were used by experts at the lowest level of categorization. (Contains 37 references, 10 tables, and 4 figures.) (DDR)

A Study of Knowledge Structure in Physics

Jennifer Discenna
Western Michigan University

April 1998
Paper Presented at AERA, San Diego, CA

Abstract

The objective of this research is to investigate the knowledge structure of the domain of physics by describing the knowledge of experts, intermediates, and novices. A review of the literature on expertise, knowledge in physics, and conceptual structure provided two competing representations of physics knowledge; one defined as a hierarchy of models, the second defined by theories.

In order to investigate these representations, a reiterative categorization task was employed using nine each novice, intermediate, and expert subjects. This task resulted in a hierarchical sort with larger piles at the top of the hierarchy and smaller piles at the bottom. The categories were classified as either theory-, model- or mathematical model-based categories. The proportions of model-, theory-, and mathematical model-based categories at each level of categorization were compared by level of expertise in order to compare the subjects' categorization with the competing models.

The representation that novices created was a hierarchy of models. The highest, most general, level for both intermediates and experts was the theory used to solve the problems. The middle and lower levels combined model- and theory-based categories. The novices' hierarchy of models was found as a subset of the intermediate representation. Model-based categories were also used by experts at the lowest level of categorization.

The results from the categorization task support a combined representation of physics knowledge based on both theories and models. In this representation, the novices' hierarchy of models is seen surrounded by a circle with the name of a theory to indicate that these models exist for experts and intermediates within the scope of the theory. The connections between the models are labeled with the principles used to solve the problems.

Introduction

Currently in science education there is a constructivist perspective to learning and teaching. In this perspective, learners are active in the their learning and knowledge acquisition is an individual process of adding new knowledge to existing knowledge in memory by creating and restructuring cognitive structures (Saunders, 1992). Cognitive structures may be thought of as an individual's beliefs, understandings, and explanations of the world that are theorized to have some organization or structure in memory (Saunders, 1992). As expertise in a certain discipline is reached, these cognitive structures become more complex and the elements of knowledge become more interconnected (Glaser, 1989). If expertise-like knowledge is the goal in science learning, then science teaching must involve aiding students in the construction of the interconnected knowledge of the domain. Therefore, in order to teach well, there is a need to understand the way in which cognitive structures in a discipline are arranged and what these structures might look like.

To investigate the knowledge structure in a particular domain, there are two important components. First, since knowledge structures consist of interconnected knowledge (Glaser, 1989), it is important to understand what the individual elements of this knowledge are for a particular domain. Secondly, since knowledge becomes more interconnected with expertise, it is necessary to understand how experts connect these elements of knowledge in order to understand the structure of the domain.

In this research, knowledge in physics will be analyzed to provide an understanding of models and theories in the domain of physics. Next, theoretical and experimental research of how these models and theories may be arranged will be discussed and models of the knowledge structure in physics will be presented. Using this theoretical basis, a study will be designed and conducted to investigate these models in terms of how the elements of knowledge are arranged by subjects at various levels of expertise. Instead of using only experts, intermediates and novices will be used to provide a contrast to the experts' knowledge structure and to situate the study within the results of other studies of expert/novice differences in physics that will be described further in this section (Chi et al, 1981; 1982; Larkin, 1981; 1983; Larkin et al, 1980a,1980b; de Jong & Ferguson-Hessler, 1986).

Knowledge in physics is primarily problem based (Hestenes, 1987); that is, the focus of a physics classroom is on solving particular problems in the discipline. Research on how individuals at various levels of expertise solve problems has been a concern of many researchers in the past decade (Larkin, 1981; 1983; Larkin et al, 1980a, 1980b). In these studies, individuals at various levels of expertise were compared in terms of the approaches that they took to solving problems in physics (Larkin, 1981; 1983; Larkin et al, 1980). It was found that experts began a problem solution by choosing a particular theory and using that theory to create a representation of that problem (Larkin, 1981; 1983; Larkin et al, 1980). Novices did not use theories, but instead represented the problems in terms of the physical objects in the problems (Larkin, 1981; 1983; Larkin et al, 1980).

In another study, subjects at various levels of expertise were asked to sort a set of physics problems and the categories that subjects made were analyzed (Chi et al, 1981; 1982). The ways in which the individuals categorized the physics problems was found to depend on their expertise. In this study, novices were found to categorize physics problems in terms of the surface features of the problems such as the objects contained in the problems whereas experts were found to organize their problems around principles used in the problem solution.

In these studies (Chi et al, 1981;1982; Larkin, 1981; 1983; Larkin et al, 1980), the experts used physics theories to represent and categorize physics problems and the novices used physical objects from the problems. The difference between experts and novices in these studies is the representations that they make of the problem situation. These differences in representations suggest differences in the nature of experts' and novices' models of physical situations. In Norman's (1983) description of models, subjects first consider a target system. This system consists of the objects and phenomenon in the situation to be modeled. A conceptual model is made of the target system that is a scientific representation of the phenomenon used by scientists and teachers to teach and understand a particular phenomenon. In essence, the difference between the experts and novices in terms of models is a difference in how the target system (physics problem) was represented. The experts represented and categorized the target system in terms of a conceptual model of the situation that aided them in problem solving whereas the novices were only able to describe the target system in terms of real world objects (Chi et al, 1981;1982; Larkin, 1981; 1983; Larkin et al, 1980).

Since the difference between experts and novices is the acquisition of conceptual models, the elements of knowledge in the domain of physics are proposed to consist of conceptualized models of physics problems. However, as highlighted by the results of Chi's (1981; 1982) categorization study, the principles used to create these conceptual models are also important to the knowledge of experts and therefore to knowledge structure in physics. Briefly, Giere (1988), a contemporary philosopher of science, proposes that theories in physics are composed of a family of conceptualized models and hypotheses linking these models to real world systems. In this framework, a theory can be thought of as a set of conceptualized models that are related to each other through a theory used to conceptualize the target domain (the physical world). The theory both defines and is defined by these models and the relationships between them and the physical world.

This representation is somewhat vague and to elaborate further, Giere (1994) proposes that theories in physics are structured in terms of models similar to the way in which concepts are arranged (Klausmeier, 1990; Rosch, 1973; 1978; Rosch et al, 1976). Concepts are proposed to be arranged in a hierarchy with more general exemplars of a concept at the top, and more specific exemplars at the bottom of the hierarchy. The number of attributes that an exemplar exhibits defines whether an exemplar is more general or more specific. For example, a dog may be a more general exemplar of a pet than a spider because a dog exhibits more of the attributes of a pet than a spider.

In this same way, Giere (1994) proposes that theories are a family of conceptualized models that are hierarchically arranged with the most general model at the top of the hierarchy and the most specific at the bottom. A general model is defined as a model that is simple conceptually. In the structure of concepts, the attributes of the exemplars define the exemplars place on the hierarchy. In the structure of models, the conceptual attributes of the model define the model's place on the hierarchy. For example, a simple pendulum consisting of mass on a string is a more general pendulum model than a pendulum consisting of a mass on a string connected to a second mass on a second string. The double pendulum is more difficult conceptually than a single pendulum and therefore is lower on the hierarchy. This representation of a theory is more elaborate than Giere's (1988) initial representation of theories as a family of models, but is still vague in terms of how the theory is explicitly represented in this family and how a more conceptually difficult model is defined.

Giere (1994) used the results from Chi's (1981) categorization study to support a representation of Mechanics models in which conservative models are more general classical mechanics models and pendulums are more specific. In this representation, the novices' categorization in Chi's (1981) study are working at an intermediate level of abstraction where the models are represented by the objects that appear in them. The experts in Chi's (1981) study understand physics more abstractly and work at a higher level on the hierarchy where the models are more general.

Giere's (1994) representation of physics knowledge as a hierarchy of models has several problems. First, this hierarchy is not supported by the method of Chi's (1981) study. Giere's (1991) hierarchy of models implies that each of the problems in Chi's study could belong to more than one pile. Larger piles of problems would have more general attributes in common to all the problems in that pile and would be higher on the hierarchy than smaller piles whose members would share more specific attributes. Chi did not investigate this reiterative type of categorization and therefore a hierarchical arrangement of models cannot be supported by Chi's results using this methodology.

In addition, this hierarchy is not supported by Chi's (1981) results with expert subjects. The principles that experts used to categorize the problems such as Newton's 2nd law or Conservation of Energy are not explicitly stated in Giere's (1994) representation. In general, it is not clear how these principles are used to define the hierarchy. It is implied that theories must have some role in determining whether a model is more general or more specific, but it is not clear from this arrangement what that role might be.

This limitation of not being able to account for the role of theories has also been linked to the Probabilistic theory of concepts (Klausmeier, 1990; Rosch, 1973; 1978; Rosch et al, 1976) from which Giere (1994) borrows. Researchers of cognitive structures have dismissed these attribute-defined structures as being unable to account for the theories that individuals use to categorize knowledge (Medin & Wattenmaker, 1984; Murphy & Medin, 1985; Spalding & Murphy, 1996). These researchers argue that the studies used to substantiate the exemplar view in which concepts are represented by exemplars arranged by their attributes were done using basic level concepts that did not require higher-level knowledge of theories (Medin & Wattenmaker, 1984; Murphy & Medin, 1985; Spalding & Murphy, 1996). The concepts used in these studies were mostly familiar objects such as furniture or birds that may be defined by attributes explicit to the objects themselves. However, other types of concepts, such as those in physics, involve more than descriptive knowledge of a category of objects. Researchers suggest (Medin & Wattenmaker, 1984; Murphy & Medin, 1985; Spalding & Murphy, 1996) that the role of theory in the structure of knowledge may be to provide links between the exemplars in the hierarchy. This view is supported by Chi's (1981) results with expert subjects in which the experts used principles used to solve the problems to categorize the problems. However, it is not supported by Chi's results from the novices' categorization.

At present, neither the Probabilistic view of models, championed by Giere (1994) in which models are arranged by their attributes, or the Coherent view (Medin & Wattenmaker, 1984; Murphy & Medin, 1985; Spalding & Murphy, 1996) in which models are linked by theories is fully supported by both the novices and experts in Chi's (1994) study. There are two ways to rectify this situation. The first is to claim that the knowledge of experts and novices in physics are completely different, with no relationship to each other. Novice knowledge of physics is entirely based on the objects in models and their attributes as in Giere's representation and expert knowledge of physics is entirely based on theories used to solve problems as in the Coherent view of knowledge.

The second way to alleviate this problem is to assert that knowledge in physics is neither entirely theory or entirely model driven. That is, at certain levels knowledge in physics is described by Giere's (1994) hierarchy of models and at other levels it is linked by the theories used to solve the problems. This is the option hypothesized in the present study. It is suggested here that both models and theories play a role in physics knowledge. Models created by the same principles or theory are clustered into groups that may have some structure. Borrowing from Giere's (1994) representation, these theory clusters may be arranged in a hierarchy of general to specific models; however, models do not build from one general model. In addition, these hierarchies of models are related to each other by specific principles used to solve the problems.

This research investigates this model by employing a categorization study using experts, intermediates, and novices in which subjects are allowed to categorize problems reiteratively. This means that the subjects will be asked to categorize the problems and then to recategorize until they are satisfied with their representation of the problem set in terms of the similarities and differences in the problems. This will result in a hierarchy of categories used to categorize the problems. These categories will then be classified as model, theory or mathematical model categories in order to determine what type of categories are used at which levels of the hierarchy.

The types of categories used across all levels of the hierarchy will be compared by expertise in order to situate this study within previous literature on expert/novice differences in problem solving (Chi et al, 1981; 1982; Larkin, 1981; 1983; Larkin et al, 1980; de Jong & Ferguson-Hessler, 1986). Next, the use of model, theory, and mathematical model categories will be compared by level of expertise to determine whether the knowledge that experts, intermediates, and novices use to categorize the problems is distinct or compatible. That is, it will be determined whether experts used completely different categories from novices and intermediates at all levels of categories. The specific research questions are as follows:

1) How do experts, intermediates, and novices compare in their use of model-, theory-, and mathematical model-based categories across all levels of categorization?

2) How do experts, intermediates, and novices compare in their use of model-, theory-, and mathematical model-based categories at each level of categorization?

Method

The subjects in this study consisted of 27 subjects at either the novice, intermediate, or expert level of expertise. Nine novice subjects participated and were defined as students who had completed only one semester of Classical Mechanics at the introductory level. Nine intermediate subjects were used who were first or second year graduate students who had completed a bachelor's degree in physics, but had not yet completed comprehensive examinations in physics. The nine expert subjects were university professors who had been involved in teaching and research in physics for at least 10 years.

The problems to be categorized consisted of 18 problems chosen from an Intermediate level classical mechanics text (Marion & Thorton, 1988) printed on colored, laminated index cards. The materials were chosen to represent typical physics problems in Mechanics. In addition, the problems were chosen such that they all could be solved using either Newton's Laws, Conservation of Energy or Conservation of Momentum. Also, all problems involve either differential equations or simultaneous equations and involve forces proportional to a constant or to distance. Finally, all problems used only a few different kinds of objects. The objects used were springs, pendulums, incline planes, pulleys and projectiles.

The goal of this study is to investigate which criteria novice, intermediate, or expert subjects use to classify problems. Towards this end, a table was created that contains all of the probable categories as determined by the researcher that subjects could make for a particular problem. These categories were then classified by the researcher as either part of a theory, model, or mathematical model. The model categories were described using Chi's (1981) classification of surface features. The first surface feature classified was the object in the problem (M-OBJ). This could have been the name of the object in the problem or a more generalized name of that object (i.e. a ball could be more generally called a projectile). Next, the attributes of the object (M-ATT) in the problem were listed. For example, an incline plane may have the attribute of having a frictionless surface. The Unknown (M-UNK) in the problem was listed directly from the problem statement. Finally, the Motion (M-MOT) of the object in the problem was determined from information about the characteristics of the object and the situation in the problem statement.

After the model characteristics were determined, the Mathematical Model (MAT-M) was determined by looking at the problem solution. The name of the mathematical method used in the solution was entered along with the complexity of the force or energy used. Other solutions were considered and other usable mathematical models were recorded.

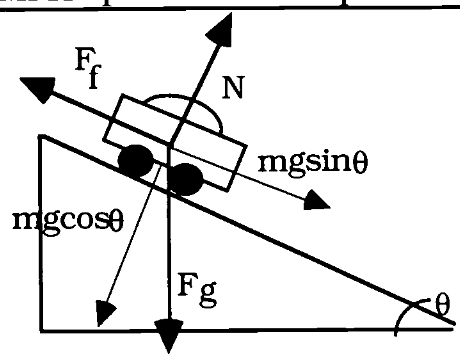
Finally, the solution of the problem was used to determine the theory used to solve the problem according to Larkin's (1983) theories about expert problem solving. In Larkin's (1983) findings experts begin the problem solving process by making a physical representation of the problem. In doing this, the experts select an appropriate schema for the problem and apply the construction and extension rules of that schema to create a physical representation that can be used to solve the problem (Larkin, 1983). Construction rules and Extension rules in Larkin's (1983) theory are inferencing rules used primarily by experts. Construction rules act on the original problem representation of the objects in the problem to produce causal agents such as specific forces, momenta, or energies (Larkin, 1983). Extension rules are used by Larkin (1983) to extend the causal model created from the application of construction rules to add new entities such as new equations of motion that facilitate problem solving. The theory-based attributes in this study then are the name of the theory or schema used to solve the problems (THE), the construction rules (THE-CON), and the extension rules (THE-EXT) of that theory.

An example of the physical representation for problem sixteen as created by the researcher is shown in Table1 along with the classifications used in that problem. The first row is the problem statement. The second row is the physical representation of that problem using Newton's Laws and the Normal, Frictional, and Gravitational forces as construction rules. The third row is the final problem solution using the equation of motion ($v^2=v_0^2 + 2ad$) as extension rules. Following this is the classification for this particular problem solution in which the object in the problem (M-OBJ) is the car, road, incline, surface and slope. The attributes of these objects (M-ATT) are the coefficient of friction and angle of the incline. The unknown (M-UNK) asked for in the problem is the velocity. The last model-based attribute is the motion of the object (M-MOT) which is linear or projectile motion. As described above, the name of the theory (THE) used here is Newton's Laws and the construction rules (THE-CON) were the Normal, Frictional, and Gravitational forces. The extension rules (THE-EXT) were the equations of motion.

Table 1

Classification of Problem Sixteen

16 An automobile driver traveling down an 8% grade slams on his brakes and skids 30 m before hitting a parked car. A lawyer hires an expert who measures the coefficient of kinetic friction between the tires and the road to be $\mu_k = 0.45$. Is the lawyer correct to accuse the driver of exceeding the 25 MPH speed limit? Explain.



$N = mg\cos\theta$

$ma = \mu_k N - mg\sin\theta$

$ma = \mu_k mg\cos\theta - mg\sin\theta$

$v^2 = v_o^2 + 2ad$

$v^2 = v_o^2 - 2dg(\mu_k \cos\theta - \sin\theta)$

v=29.96 MPH

Classification	Problem Attribute
M-OBJ	Car, Road, Incline, Surface, Slope
M-ATT	Coefficient of Friction, Angle
M-UNK	Velocity
M-MOT	Linear or Projectile Motion
MTH-M	Constant Force, F=c
THE	Newton's Laws
THE-CON	Gravitational, Normal, & Friction Force
THE-EXT	Equations of Motion

In order to determine the validity of the classifications of the attributes in the problems as model, theory, or mathematical model-based, the problems were given to a physics expert who did not participate in the study as a subject. The percent agreement between the researcher and the expert was 97.8%. All disagreements were resolved by removing some categories from the table.

Procedure

Subjects were tested individually. Cards were randomly ordered and presented in a pile in front of the subject. A video camera was focused to include only the cards on the table. The video camera was then turned on and subjects were instructed to use their knowledge of physics to put the problems into groupings or categories based on their meaningful similarities and then to go back and make bigger or smaller piles until they had included everything that they thought was important to know about the problems.

The subjects then began reading through the cards one by one and putting the cards into piles. The subject was prompted, if necessary, to think aloud about the names of the categories. Once the subjects had read all the cards, categorized them and named their respective categories, they were prompted (if necessary) to make bigger or smaller categories if they felt it was necessary to understanding the problems. The subjects then either stayed with those categories or combined piles or separated them. At the end of this pass, they were prompted again, if necessary to make bigger or smaller categories. Again, the subjects either stopped or continued to recombine the cards.

Audio tapes from the resulting videotapes of the task were transcribed verbatim. The videotapes were viewed with the transcripts in order to add references to particular cards, the movement of cards into piles, removal of cards from piles, and references to particular piles. The protocols were divided into segments reflecting each change in the piles. These changes included placing a card into a pile, removing a card from a pile, combining piles, or explaining the name of a pile if it had not already been explained. A second set of information is attached to the end of each protocol and is again organized by segment numbers. This table provides a diagrammatic representation of the status of the piles during each segment. The diagrammatic representation consists of numbers surrounded by a box representing piles and their contents. Arrows were made between boxes to show that the contents of pile in the lower box was once a part of the larger pile in the top box. Changes made during the segment are highlighted by showing the new card number in boldface and by a thickened perimeter of the box containing the new card.

A grid consisting of three columns indicating the level (High, Middle, or Low) at which the cards were classified was made for each subject. In the task, the cards were sorted into increasingly larger or smaller piles as determined by the subject. These piles correspond to a hierarchy that is arranged from general attributes to specific. For this reason, piles which have a general attribute in common are at a higher level than piles with more specific attributes. In other words, piles that are larger are more general and therefore at a higher level than piles that are smaller. The "High" level piles have the most members and therefore the attribute that these cards have in common is the most general. The "Low" level piles are the smallest and contain the fewest members. The attribute that this smaller number of cards has in common is more specific. The "Middle" level piles are larger than the "Low" level piles and the attribute that the cards share is more general. The "Middle" level piles are smaller than the "High" level piles and are therefore have more specific attributes in common.

In the data grids, the High, Middle and Low level columns are divided into two sub-columns. An example of this is shown in Table 2. The larger of the two columns indicates the name given to the card at that level by the subject and the segment where that card was classified into that level or when the category was given name, For example, in segment 2.10 in Table 3.2, the pile that card 5 shares with cards 15,17, and 18 is called "Harmonic Motion" therefore, the name Harmonic Motion with the segment number 2.10 is recorded in the first column in the Middle category. These names were then classification in terms of model, theory, and mathematical model categories and the code for the classification was recorded in the smaller of the two columns. For problem five, the name "Harmonic Motion" was found in under the model sub-classification of the motion of the object and therefore the code M-MOT was recorded in the second column in the "Middle" category.

Table 2

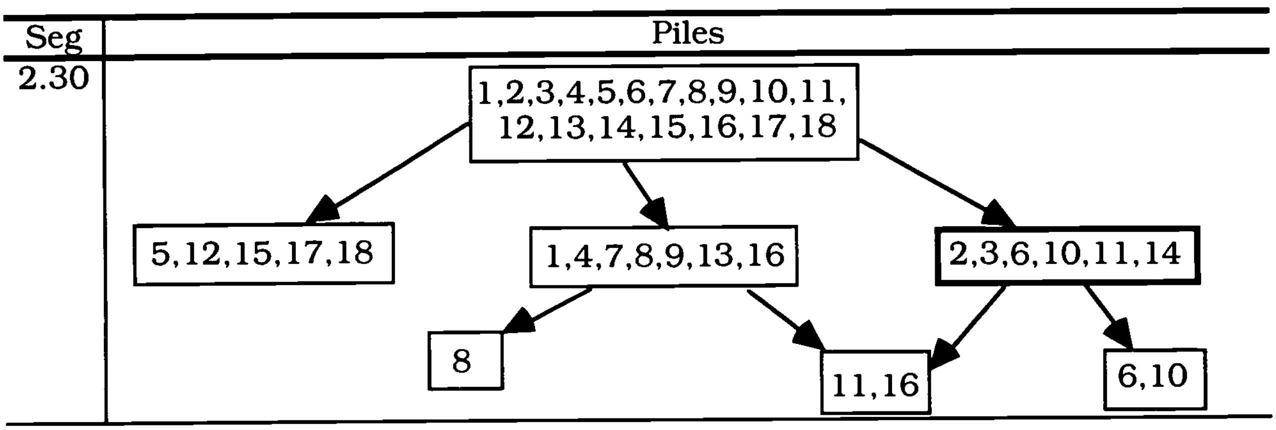
Partial Data Grid for Expert 1

Subject	Expert 1					
Level Card #	High		Middle		Low	
5	Mechanics 1.3	THE	Harmonic Mot. 2.9	M-MOT		
6	Mechanics 1.3	THE	Kinematics 2.25	THE-EXT	Momentum 2.24	THE-CON
7	Mechanics 1.3	THE	Friction 2.9, 2,11	THE-CON		

The level of categorization was determined by inspecting the final diagrammatic representation for each subject. Most subjects made between two and three recombinations, meaning that they placed the card into two to three increasing larger piles. The number of levels can be determined by counting the number of arrows for a particular card. For example, the final diagrammatic representation for Expert 1 is shown in Table 3. In the representation in segment 2.11, card number 6 belongs to three different piles and the number appears in three different boxes. Therefore, the number of levels for card 6 is three. In segment 2.11 in Table 3.5, card number 6 belongs to a High level pile that included all the cards and then belongs to a Middle level pile that also included cards 2, 3, 10, 11, and 14. Finally, card number six was belongs to a small, Low level pile with card ten only. In the data grid in Table 2, card six has entries in the High, Middle and Low level columns that refer to the names and segments where it was placed into the large, middle and small piles referred to above.

Table 3

Final Diagrammatic Representation for Expert 1



The second task was to determine if the levels were High, Middle, or Low. As discussed above, it is expected that cards that belong to large piles have very general characteristics in common with the other cards in that pile; a pile in the High level is the largest and therefore it likely includes the most general attributes in the hierarchy. As the piles get smaller, the characteristics that the cards share become less general and more specific; a pile in the Low level is the smallest and therefore it likely includes the most specific attributes. In this research, it is necessary to compare these classifications at each level to determine which features of the problem are used to define general or specific characteristics with respect to expertise. In order to compare subjects' respective categorization, a convention was developed to classify High, Middle, and Low levels. It was decided that levels would be classified from Low to High, unless the subject had a category that included the entire set of cards, then classification would go from High to Low.

The reason for the Low to High convention stems from Rosch's (1978) work on categorization. In this theory, knowledge is categorized hierarchically with more specific attributes at the bottom of the hierarchy and more general ones at the top (Rosch, 1978). In the middle there exists a "Basic" level that is neither the most general nor the most specific (Rosch, 1978). In Chi et al's (1982) study of hierarchical categorization, the novices were unable to make High level categories that the experts were able to make. It was hypothesized that the novices were working at Rosch's (1978) basic level and were unable to make higher levels because they had not learned to abstract the attributes of the members of the basic level (Chi et al, 1982). This suggests that learning may be a matter of learning to abstract the attributes and create higher level categories with more general attributes. Therefore, the learning process starts from the most specific categories to the more general. In order to show this progression from more specific categories to more general and compare the categorizations of subjects with different levels of expertise, the piles were ordered from Low to High or from specific to general. It is expected that novices, for example, will only have Middle and Low level categories as they did in Chi et al's (1982) study.

The second part of the convention, if subjects have a category that includes all the cards then the piles are ordered from High to Low, was created in the case that subjects at different levels of expertise have only two levels. The purpose of separating by level of categorization is to compare the attributes at different levels of abstraction for subjects at different levels of expertise. The assumption is that subjects create piles from the most specific attributes to the most general or Low to High. However, a pile that includes all the cards is necessarily at the highest level of abstraction, even if there are only two levels in the categorization. Therefore, the attribute which all the cards share must be the most general attribute for the set and must be compared to other subjects High level categories. The second part of the convention attempts to assure that all piles that are High level piles are the most abstract.

Once the level for each card was determined, the protocol was scanned for the segment in which that card or pile was named or classified for that level. Next, the segment was read to determine the name of that pile. The name indicated for that pile was then recorded in the same column with the segment number. Finally, the name that the subject gave was coded in terms of the coding scheme . That is, each name was classified as either model-based (M), mathematical model-based (MAT-M), theory-based (THE) or other (OTH). The model-based categories are sub-classified into the object in the model (M-OBJ), the attribute of that object (M-ATT), the unknown in the problem (M-UNK) or the motion of the object (M-MOT). The theory-based classifications also include the construction rules (THE-CON) and extension-rules (THE-EXT). For example, for problem number five in Table 2, the name "Harmonic Motion" is coded as a Model- based attribute referring to the motion of the object (M-OBJ).

In order to establish reliability for this coding scheme a second coder unfamiliar with the study was given approximately 30% (eight protocols) to analyze. The inter-rater reliability obtained was 91% for agreement between the researcher and the coder.

Results

The data for this research consists of a grid for each subject which displays the classification for each card according to the table as either Model-, Theory-, or Mathematical Model-based and the level at which the card was categorized. The level refers to the size of the pile or the generality of the attribute that the cards in that pile have in common. More general attributes are assigned to piles that are larger and are listed at the High level. Smaller piles have more specific attributes in common and are listed at the Low level. Proportions were calculated for each of the Model-, Theory-, and Mathematical Model-based classifications over both the total number of classifications as well as the number of classifications at each level. These proportions comprise the data for this analysis.

There are three variables in this study to use in the analysis: level of expertise, level of categorization, and classification. The level of expertise can be expert, intermediate, or novice. The level of categorization can be high, middle, or low. The classifications can be Theory-, Model-, or Mathematical Model-based. These three variables are used in this study to answer questions about the structure of knowledge of experts, intermediates, and novices. In particular, this analysis will answer the following general questions:

1. How do the classifications that experts, intermediates, and novices use compare across levels of categorization?

2. How do the classifications that experts, intermediates, and novices use compare by level of classification?

Analysis of Classifications Across All Levels

The first analysis compares classifications by subjects pooling over all levels of categorization. In this analysis, proportions of Model-, Theory-, and Mathematical Model-based classifications over the total number of classifications were calculated. The mean proportion of Model-, Theory-, and Mathematical Model-based categories over the total number of classifications are graphed in Figure 1. This measure shows what general category the subjects of varying levels of expertise used to classify the problems. A Multivariate analysis was conducted with level of expertise as the independent variable and Theory-, Model-, and Mathematical Model-based classifications as the dependent variables. Tests of significance for this analysis were found to be significant (F=4.48, p=0.001).

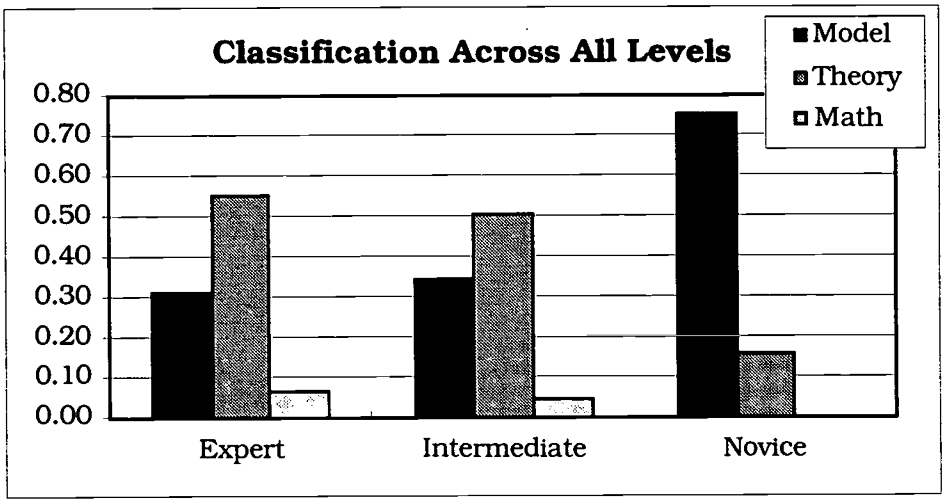


Figure 1. Classification Across All Levels

The Multivariate test was significant, indicating that there is a difference in the vectors representing the mean proportions of Theory, Model, and Mathematical Model attributes used by Experts, Intermediates, and Novices. Next, an analysis of variance was conducted for each of the dependent variables: Model-, Theory-, and Mathematical Model-based classifications with level of expertise as the independent variable in order to determine where the significant differences lie. The Mathematical Model classification was rarely used by any subjects and use was not significantly different across expertise (X_E=0.07, X_I=0.05, X_N=0.00, F=1.03, p=0.373, ns). However, significant differences were found on the ANOVA for proportions of Theory-based classifications across the three levels of expertise (X_E=0.56, X_I=0.50, X_N=0.16, F=11.22, p=0.000). To determine which of the three groups were significant from each other, a Tukey-HSD test with significance level at 0.05 was conducted. Here it was found that the proportions of Theory-based classifications made by intermediates and experts was significantly greater than novices. No other differences were found. These results are summarized in Table 4.

Table 4

Theory- and Model-based Classifications Across All Levels

Mean		Expert	Intermediate	Novice
0.5556	Expert			
0.5044	Intermediate			
0.1622	Novice	*	*	

*$p<0.05$

The analysis of variance for the proportions of categories classified as Model-based over all the categories used for experts, intermediates, and novices was also significant ($X_E=0.31$, $X_I=0.34$, $X_N=0.75$, $F=17.19$, $p=0.000$). A Tukey-HSD test with significance level at 0.05 was run to determine which groups were significantly different from each other. Here it was found that novices used a significantly larger proportion of Model-based categories than did either experts or intermediates. No other differences were found. These results are summarized in Table 5.

Table 5

Model-based Classifications Across All Levels

Mean		Expert	Intermediate	Novice
0.3111	Expert			
0.3444	Intermediate			
0.7556	Novice	*	*	

*$p<0.05$

Analysis of Classifications Separated by Level of Categorization

Next, the hierarchical nature of the data was addressed. Proportions of Theory-, Model-, and Mathematical Model-based classifications over the total number of classifications at each level of categorization were calculated and compared for experts, intermediates, and novices. These analyses were conducted to provide information about how the categories used by experts, intermediates, and novices differed at each level of categorization, namely, High, Middle, and Low. Categorizations by subjects at each of these levels will be analyzed in turn.

Analysis of Classifications at the High Level of Categorization

The first analysis compares the proportions of categories classified as Theory-, Model, and Mathematical Model-based over the total number of classifications at the High level of categorization made by experts, intermediates, and novices. Figure 2 shows the mean proportions of Model-, Theory-, and Mathematical Model-based classifications over all classifications made at the High level of categorization for each level of expertise. As this graph demonstrates, all of the classifications that were made at the High i.e., most general level, were Theory-based. Model- and Mathematical Model-based classifications were not used at this level. The Multivariate analysis was not conducted since there was only one classification used by the subjects at this level of categorization. Instead, an analysis of the variance was conducted with proportions of Theory-based classifications over the total number of classifications made by expert, intermediate, and novice subjects at the High level of categorization. This analysis was significant for the use of theory-based classifications at the High level categorization by expert, intermediate, and novice subjects (X_E=0.76, X_I=0.44, X_N=0.00, $\underline{F}$=8.45, $\underline{p}$=0.000).

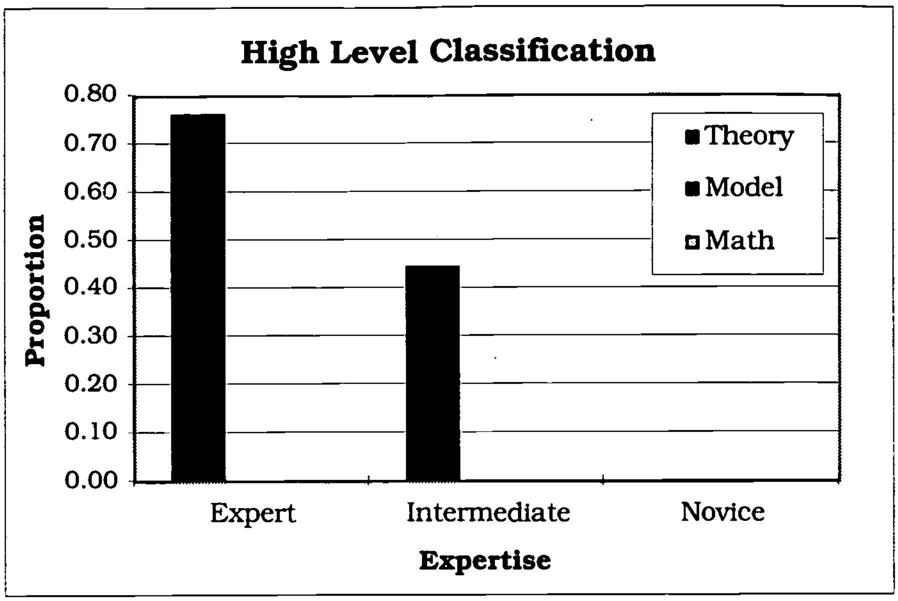


Figure 2. Classification at the High Level of Categorization

The analysis of the variance was significant which indicates a statistically significant difference between the proportion of categories classified as theory-based at the High level of categorization made by experts, intermediates, and novices. To determine which groups are statistically different, a Tukey-HSD test with significance level at 0.05 was executed and no significant differences were found between experts and intermediates on use of Theory-based classifications at this level. However, it was found proportions of categories classified as Theory-based were greater at the high level of categorization for experts than for novices. These results are summarized in Table 6.

Table 6

Theory-based Proportions at High Level

Mean		Expert	Intermediate	Novice
0.7578	Expert			
0.4444	Intermediate			
0.0000	Novice	*		

*$p<0.05$

Analysis of Classifications at the Middle Level of Categorization

The next analysis compares the proportions of categories classified as Theory-, Model, and Mathematical Model-based over the total number of classifications at the Middle level of categorization made by experts, intermediates, and novices. The mean proportions of Model-, Theory-, and Mathematical Model-based classifications over all classifications made at the Middle level are shown for each level of expertise in Figure 3. A Multivariate analysis of variance was conducted with level of expertise as the independent variable and Theory-, Model-, and Mathematical Model-based classifications as the dependent variables. Tests of significance for this analysis were conducted and were significant ($F= 2.47$, $p=0.038$) indicating a difference in the proportions of categories classified as Theory-, Model-, or Mathematical Model-based used by expert, intermediate, and novice subjects.

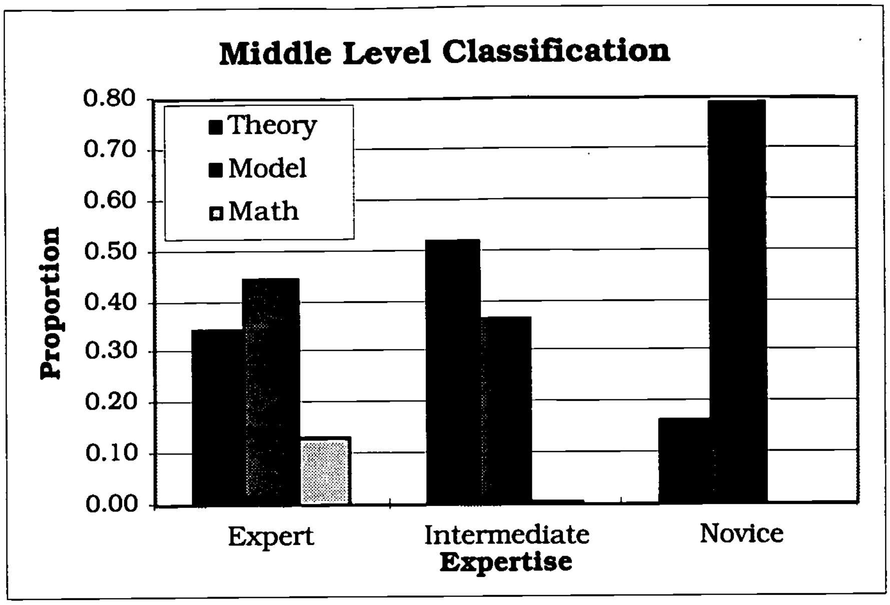


Figure 3. Classification at Middle Level

An analysis of variance was conducted for each of the dependent variables; namely, Model-, Theory-, and Mathematical Model-based classifications with level of expertise as the independent variable in order to determine which of the dependent variables are significantly different for expert, intermediate, and novice subjects. The use of Model-based classifications was found to be significant at the Middle level categorization between experts, intermediates, and novices (X_E=0.44, X_I=0.37, X_N=0.79, F=5.22, p=0.013). To determine which of the three groups were significant from each other, a Tukey-HSD test with significance level at 0.05 was conducted. Significant differences were found between intermediates and novices for Model-based classifications indicating that proportions of Model-based classifications were significantly greater for novices than for intermediates. No other significant differences were found for the proportion of Model-based attributes used by experts, intermediates, and novices. These results are summarized in Table 7.

Table 7

Model-based Proportions at Middle Level

Mean		Expert	Intermediate	Novice
0.4456	Expert			
0.3656	Intermediate			
0.7889	Novice		*	

*$p<0.05$

The analysis of variance using proportions of Theory-based categories over the total number of categories at the Middle level as a dependent variable and expertise as an independent variable was also found to be significant ($X_E=0.34$, $X_I=0.52$, $X_N=0.17$, $F=4.11$, $p=0.029$) indicating a difference in the use of Theory-based classifications between experts, intermediates, and novices. To determine which of the three groups were difference, a Tukey-HSD test with significance level at 0.05 was executed. No differences were found between experts and intermediates on use of Theory-based classifications at this level; however, significant differences were found between intermediates and novices for Theory-based classifications indicating that intermediates used Theory-based classifications significantly more than novices. These results are summarized in Table 8.

Table 8

Theory-based Proportions at Middle Level

Mean		Expert	Intermediate	Novice
0.3456	Expert			
0.5178	Intermediate			
0.1656	Novice		*	

*$p<0.05$

The analysis of variance using proportions of Mathematical Model-based categories over the total number of categories at the Middle level as a dependent variable and expertise as an independent variable was not found to be significant (X_E=0.13, X_I=0.01, X_N=0.00, F=2.91, p=0.07, ns) indicating no differences in the use of Mathematical Model-based classifications between experts, intermediates, and novices. However, the result of this test was very close to the 0.05 significance level and it might be expected that if more subjects were used, significance may have been reached.

Analysis of Classifications at the Low Level of Categorization

In the last analysis, comparisons are made between the proportions of categories classified as Theory-, Model, and Mathematical Model-based over the total number of classifications at the Low level of categorization by level of expertise. The mean proportions of Model-, Theory-, and Mathematical Model-based classifications over all classifications made at the Low level of categorization are shown for each level of expertise in Figure 4. This is the level in which the piles were the smallest and the attributes the cards had in common were the most specific. A Multivariate analysis was conducted. Tests of significance for this analysis were conducted and were not significant (F= 2.1948, p=0.061, ns) indicating no differences in the use of categories classified as Theory-, Model-, or Mathematical Model-based between experts, intermediates, and novices at this level of categorization.

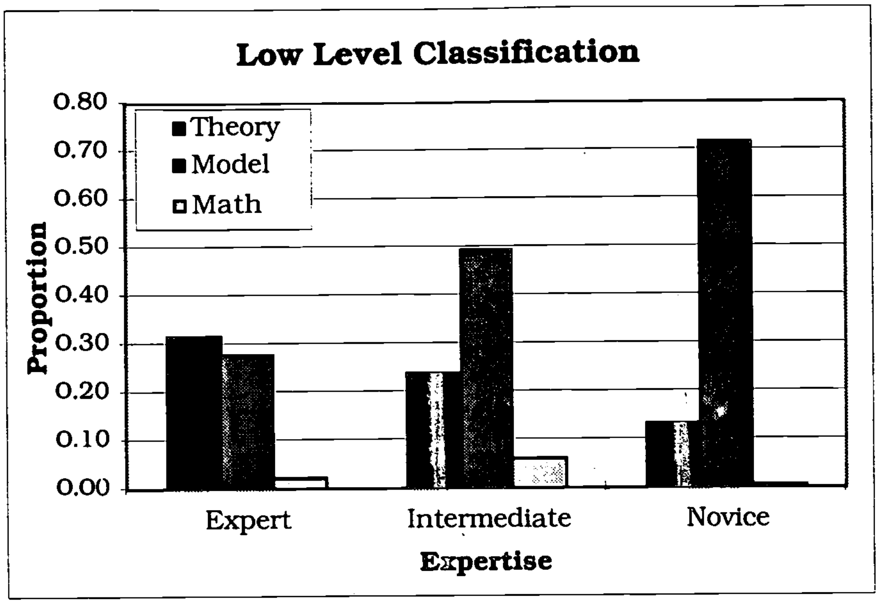


Figure 4. Classification at Low Level

Although tests of significance for the Multivariate tests were not significant, the probability was very close to the 0.05 significance level. Since the Multivariate test is conservative and that there are few subjects in this analysis, an analysis of variance was conducted in order to indicate any trends between the use of Model-, Theory-, and Mathematical Model-based attributes between expert, intermediate, and novice subjects at the low level of categorization. The use of Model-based classifications was found to be significant at the low level of categorization between experts, intermediates, and novices (X_E=0.28, X_I=0.49, X_N=0.71, F=6.08, p=0.007). To determine which of the three groups were significant from each other, a Tukey-HSD test with significance level at 0.05 was conducted. Significant differences were found between experts and novices on the use of Model-based classifications indicating that experts used Model-based categories. No other significant differences were found for the proportion of Model-based attributes used by experts, intermediates, and novices. These results are summarized in Table 9.

Table 9

Model-based Proportions at Low Level

Mean		Expert	Intermediate	Novice
0.2800	Expert			
0.4956	Intermediate			
0.7144	Novice	*		

*$p<0.05$

The analysis of variance using proportions of Theory-based categories over the total number of categories made at the Low level as a dependent variable and expertise as an independent variable was not found to be significant ($X_E=0.32$, $X_I=0.24$, $X_N=0.13$, $F=2.00$, $p=0.157$, ns) indicating no differences in the use of Theory-based classifications between experts, intermediates, and novices. Similarly, the analysis of variance for the proportion of categories classified as Mathematical Model-based used by experts, intermediates, and novices was not found to be significant ($X_E=0.02$, $X_I=0.06$, $X_N=0.01$, $F=0.73$, $p=0.492$, ns) indicating no differences between experts, intermediates, and novices in the use of Mathematical Model-based categories.

Summary of Analyses of Classifications at Each Level of Categorization

Table 10 shows a summary of the results of the previous analyses comparing the proportions of Model, Theory and Mathematical Model classifications over the total number of classifications made by experts, intermediates, and novices at each level of categorization The rows indicate the level of expertise of the subjects as either expert, intermediate or novice. The columns indicate the level of categorization as either High, Middle or Low. Recall that the High level of categorization is the level which contains the largest piles the subjects made and thus the attribute which all of cards in those pile have in common is the most general. The Low level of categorization contain the smallest piles with the most specific attributes in common.

The Columns are separated into Theory (THE) and Model (MOD) sub headings. Under each sub heading is the proportion of categories made by each group of subjects classified as Model- or Theory-based at each level of categorization. Also, the proportion is bolded to indicate that use of that classification was found to be statistically significant. In the last row the Table number where the statistical finding is summarized is entered. For example, at the Middle level for intermediates the proportion of categories classified as Theory-based (THE) is 0.52. This proportion of Theory-based categories for intermediates is significantly higher as compared to novices at this same level where only 0.16 of their classifications are theory-based. This information is summarized in Table 8. The proportions of Mathematical Model-based attributes was not included in this summary since that classification was not used much by any group and use of this classification was not significant in any of the analyses.

Table 10

Summary of Results of Analysis of Classifications
Separated by Level

	HIGH		MIDDLE		LOW	
	THE	MOD	THE	MOD	THE	MOD
EXPERT	**0.76**	0.00	0.35	0.45	0.32	**0.28**
INTERMEDIATE	0.44	0.00	**0.52**	**0.37**	0.24	0.50
NOVICE	**0.00**	0.00	**0.16**	**0.79**	0.13	**0.71**
Table	6		8	7		9

DISCUSSION

The main objective in this study is to describe knowledge structure in physics by comparing the knowledge of individuals at varying levels of expertise. Towards this end, subjects were asked to categorize a set of physics problems and were then asked to re-categorize the problems more than once into bigger or smaller categories. In this way, the subjects created a hierarchy of categories to which the problems belonged. In order to make comparisons between the types of categories subjects made and the level of expertise of the subjects, a classification system was created and can be seen in the appendix.

In studying the knowledge structure of experts, intermediates, and novices, there were two objectives. The first objective was to describe the differences between the classifications by experts, intermediates, and novices across all levels of categorization and compare it to the existing literature. This will reify the findings of other research and situate the current study as an extension of these results. Since the major differences between experts and novices in the categorization literature stemmed from their knowledge of models and theories (Chi et al, 1981; 1982; deJong & Ferguson-Hessler, 1986; Veldhuis, 1990), the comparisons between the levels of expertise will be made in terms of model-, theory-, and mathematical model classifications. The second objective was to compare the theory-, model-, and mathematical model-based classifications made by experts, intermediates, and novices at each level of categorization. These findings are used to support and extend theoretical and empirical accounts of knowledge in physics in terms of two competing views of knowledge from the literature (Giere, 1988; 1994; Medin & Wattenmaker, 1984; Murphy & Medin, 1985; Spalding & Murphy, 1996).

The results showed how experts, intermediates, and novices differed statistically in terms of the way they categorized the problems. These results will be discussed in terms of the objectives stated above. In addition to this, there will be a discussion of implications for teaching in physics.

Classifications Across All Levels

The first objective was to compare the proportions of Model-, Theory-, and Mathematical Model-based classifications of all the classifications made by pooling over all the levels of categorization. The rationale for this objective was to situate the current research within previous research on expert/novice categorization and problem representation (Chi et al, 1981; 1982; deJong & Ferguson-Hessler, 1986; Larkin, 1983; 1985; Larkin et al 1980a; 1980b; Veldhuis, 1990).

The results confirm the hypotheses regarding both the novices' and experts' categorizations. The results validate previous research findings in that experts used theory-based classifications more than did the novices (Chi et al, 1981; 1982; deJong & Ferguson-Hessler, 1986; Veldhuis, 1990). These theory-based attributes include the theory and the inferencing rules used to solve the problems.

It is also not surprising that the novices in this study used Model-based attributes to categorize the problems more than experts. These Model-based attributes include the surface features of the problems. These results are in accordance with those of other categorization experiments (Chi et al, 1981; 1982; deJong & Ferguson-Hessler, 1986; Veldhuis, 1990) and investigations of problem representation (Larkin, 1983; 1985; Larkin et al 1980a; 1980b) in which experts represent and categorize problems in terms of physical quantities used to solve problems and Novices represent and categorize problems in terms of the actual objects in the problems.

The results of the categorization of the intermediate subjects was different than expected in terms of the use of mathematical model-based classifications. In general, the results showed that the mathematical model-based category, i.e. the mathematical methods, sophistication, was used less often than the other category was used by all the subjects. It was expected that intermediates would use this category because the difference between Introductory and Advanced Mechanics lies in the sophistication of the mathematical methods involved. In Introductory Mechanics, the mathematical sophistication is limited to algebra, geometry, and basic calculus. Advanced Mechanics requires the use of the linear algebra, multivariable calculus, and differential equations. It was expected then that the intermediates would categorize the problems according to the attributes of the problems that were causing them the most difficulty. Yet, this was not the case. The mathematical model-based category was not used much by any group of subjects. Instead, intermediates categorized in generally the same way as experts in terms of using theories to categorize the problems more than novices.

Many of the previous categorization studies used graduate students as experts participants(Chi et al, 1981; 1982) . In this research, graduate students were not classified as experts, rather were used as intermediates. This was done in accordance with the expertise literature which defines an expert as an individual with approximately 10 years of experience in a particular field (Ericsson & Smith, 1991). In addition, the problems used in the current study were at the an intermediate level, rather than at the introductory level used in other studies (Chi et al, 1981; 1982; deJong & Ferguson-Hessler, 1986; Veldhuis, 1990). For this reason, it might be expected that graduate students are experts at solving introductory level problems, however, some differences might have been expected between intermediates and experts in using harder problems that required the subjects to use their advanced knowledge of physics.

These results replicate those of other studies and support the idea that experts and novices used their knowledge of physics to represent and categorize the problems. However, the knowledge of physics that the subjects used to categorize the problems was qualitatively different. From these data, it appears that the knowledge that the novices used is dependent on the attributes of the models used to solve the problems; whereas the knowledge that the experts and intermediates use is centered on the principles. Principles compose the theories that are used to solve the problems and to create the models. Models refer to the representations that are made of a problem situation. The result that experts and intermediates use principles to categorize the problems may indicate a better understanding of how the problems are solved; whereas the novices use of Model-based attributes suggest that the knowledge that novices have is centered around the finished products of problem solving.

Classifications Separated by Level

The first part of the data analysis allowed for an investigation of the general nature of all the classifications that subjects made in terms of theory-, model-, and mathematical model-based attributes used to solve the problems. In this analysis, these results are extended to include the hierarchical nature of the subject's categorization. In these analyses, comparisons were made between novice, intermediates, and experts use of model-, theory-, and mathematical model-based attributes at each level of categorization. The rationale for this objective is to investigate the competing models of knowledge in physics. As discussed earlier, Giere (1994) proposed that physics knowledge consists of a hierarchy of models that are structured with more general models at the top of the hierarchy and more specific ones at the bottom. Medin and Murphy (Medin & Wattenmaker, 1984; Murphy & Medin, 1985; Spalding & Murphy, 1996) suggest that in order to account for the coherence of category construction for knowledge in general, the role of theories in knowledge structure must be taken into account. In this view, models are structured according to the theories used to create them.

The categorizations of the novices in this study was well predicted by the hypotheses and by Giere's (1994) hierarchical representation of models. The result that the novices' hierarchy was entirely composed of model-based attributes as compared to experts and intermediates whose categorizations were mixed between models and theories at lower levels supports a representation of the novices' knowledge as a structure of models. The result that novices were unable to make "High" level categories has also been found by Chi et al (1982). These results may also support Giere's (1994) assertion that novices are acting at a "Basic Level" where models have the most visual similarity to each other. It could be explained that the novices in the current study were focused on the visual similarity, such as the objects in the problems, between the models and are not able to abstract any further than the Basic level. This explains why novices in this study used more model-based attributes to categorize the problems and create their hierarchy as compared to experts and intermediates.

Results of the classifications that intermediates used in the present study are not predicted by the hypotheses in that mathematical model-based categories were not used to classify the problems at any level of categorization.

The experts categorizations were predicted by the hypotheses above in that experts used theory-based categories at all levels of categorization and model-based categories at lower levels of categorization.

One possible reason why novices did not use many theory-based attributes may have been that problems in physics, such as the ones used in the study, are not real problems to students in that they do not represent theories of how the world works. As discussed earlier, the physics problems that students are presented with are based on models that are ready-made. Novices do not have many opportunities to engage in the interpretation of phenomenon or to use any theories; naive or otherwise. These students may view problems as artificial in that they do not relate to real situations. Since they do not see explanation as part of the problem solving or representation phase in solving physics problems, they may not use their naive theories to explain the problems. The question of whether novices have theories can not be answered by this research because it did not ask them directly about their understanding of phenomenon. However, it is apparent that novices do not use these naive theories to categorize problems in the domain of physics. Experts and intermediates, in contrast, realize that problems relate to "real" situations. They understand the formal physics theories used to solve problems and therefore use Theory-based classifications.

Neither of Giere's (1994), nor the Coherent views of physics knowledge are sufficient to explain the results of all the categorizations in this study. The novices' categorization is accurately predicted by Giere (1994) in that they categorized the problems into a hierarchy of models. The intermediates' and experts' categorizations also has elements of this hierarchy in that model-based categories are used at the middle and low levels. Experts and intermediates used theory-attributes to categorize the problems. The use of theory-based attributes is predicted by the Coherent view of category construction (Medin & Wattenmaker, 1984; Murphy & Medin, 1985; Spalding & Murphy, 1996).

Recall that there were two proposals of how to resolve this situation. The first was to propose that the knowledge of experts, intermediates, and novices is distinct in terms of their use of models and theories to represent problems. This was not the option expected and it is not supported by the results of this study. In this study, novices used model-based attributes to categorize the problems at all levels of categorization, but the experts and intermediates also used model-based attributes at lower levels of categorization. It is suggested from these results that the categories used by experts, intermediates, and novices overlap at lower levels of categorization.

There is a second proposal regarding how to resolve the problem that neither the Coherent view of category construction (Medin & Wattenmaker, 1984; Murphy & Medin, 1985; Spalding & Murphy, 1996) which proposes a theory-driven structure of knowledge, nor Giere's (1994) structure of models can explain the categorization of both the novices and the intermediates and experts in this or previous categorization studies (Chi et al, 1981; 1982). This proposal suggested that knowledge may be best described as a combined view driven by both theories and models. In this view, there are clusters of hierarchies of models connected by the theories used to create them. The results from the intermediates' and experts' use of both theory-and model-based categorizations give support to this proposal. However, it is not clear whether the use of theory- or model-based attributes is hierarchical in that more general model- or theory-based categories are used at higher levels than at lower levels. This more descriptive question is left for future research.

Implications for Teaching

This research also has implications for physics pedagogy. The understanding of the connections between models and theories at different levels of expertise gained from this study may be useful as a model of knowledge in physics to be used in the classroom. The Classical and Probabilistic views of concepts have been used to explain how concepts are learned both in Klausmeier's (1990) and Ausubel's work (1963) and to explain conceptual change in work by Chi, Slotta and de Leeuw (1994). Briefly, in Klausmeier's scheme, learning a concept depends on learning the attributes of the concept, and differentiating these attributes. For Chi et al (1994), conceptual change is the process of re-categorizing a concept from its incorrect to correct ontological tree.

In physics, learning may be viewed in terms of the knowledge structure elaborated on in the present research. In particular, learning a physics theory may depend on learning the conceptual models that compose the hierarchies by differentiating them from each other in terms of their attributes. Many researchers have used models in order to teach theories in physics (Brown, 1993; Brown & Clement, 1989; Halloun, 1995; 1996; Halloun & Hestenes, 1985; 1987; Hestenes, 1987; 1992; White, 1993; White & Frederiksen, 1990). Hestenes and Halloun provide a very detailed description for instruction using modeling techniques. Brown and Clements' use teaching models or analogies to facilitate students to change their mental models into scientific models. Finally White and Frederiksen have developed a computer tool to help students investigate model development in physics.

Researchers have suggested that novices not only need knowledge of physics models, but they also need to know how to connect these models into coherent theories (deJong & Ferguson-Hessler, 1986; Robertson, 1990). This suggestion is also substantiated by the results of this study. As the results of this study indicate, novice subjects have been successful in structuring the conceptualized models in physics into hierarchies. However, these subjects were not successful in connecting these models together in terms of a theory. In order to remedy this situation, it may be possible to use the representation of knowledge described in this research to make students aware of the role of theories in model-making. A description of such an attempt is described in the following section.

Physical Science in Preservice Elementary Education - SCI 180

The representation of models organized into families connected by the theories that created them has been used to facilitate meaningful learning experiences in the physics course for pre-service Elementary Education students at Western Michigan University. The representation described earlier was used to create a "Model Map." A Model Map is a set of models chosen to represent a particular theory, that are connected by the principles used to create them and clustered into hierarchies defined by the attributes of the conceptualized model. A sample Model Map for the section on "Motion" is included in the appendix.

The Model Map was created in order to organize and structure the content of the course. The course itself is organized around activities in which phenomenon are presented to students as problems. The students are given the task of describing and explaining the phenomena, or making models. Problems or phenomena are chosen to represent the most inclusive models and the key parts of the theory. For example, the Model Map for the motion section consists of four basic models which compose the "object" level of the hierarchies: Stomper Car, Incline Car, Hot Wheels Car and Free Fall. These are basic objects that illustrate the basic models that can be made using Newton's Laws. The Stomper Car is a battery operated car that has a constant velocity and is an example of an object that is in motion, but whose motion does not change. The Free Fall object is acted on only by gravity, which is a simple example of Newton's 2nd Law. The Incline Car adds the normal force to the force of gravity. Many students infer the normal force from some wording of Newton's 3rd Law. Finally, the Hot Wheels Car adds friction to the model.

The four basic models have both higher and lower level models attached to them which are more abstract and more specific respectively. The two higher level models describe the two kinds of motion that are exhibited in these four objects. One is the case of an object with no external forces where the velocity is constant. The second is the case where the external force is non-zero and constant, and the velocity is changing. The lower level models are more conceptually difficult situations that use the four basic level models. For example, the model for The Jump is identical to the Free Fall model except that it involves an object rising as well as falling. Also, the object in The Jump moves in two dimensions. However, the model itself only involves the force of gravity as in the Free Fall model. All of the models in the motion section combine to illustrate Newton's Laws.

This organization is constructed by the learners through inquiry experiences. During the first weeks of the course, students work together in groups of four and as a class on describing the motion of the objects in the four main models. When the students have become comfortable with the concepts of distance, time, velocity and acceleration and particularly with the graphs associated with these concepts, they are asked to ponder the question of why things move the way that they do. Many of these students have had some prior experience with the idea of force and with Newton's Laws and many suggest this as the reason for the motion. However, knowing that Newton's Laws explain the motion is much easier than knowing how!

After the students have created the complete models for the four main types of motion, they are given a problem solving activity. The activity required students to make models of a toy car traveling along The Dip, The Jump and then Sinking. The students are asked to describe and explain the motion of the object in their groups of four and present their model to the class. One model that causes particular problems is The Dip. The velocity vs. time graph shows a changing acceleration. This is the first time that acceleration has not been constant. The students usually decide that The Dip is just two Incline Cars front to front. However, this usually causes them to model the acceleration as being constant on the way up and constant on the way down. Instead of having a curved dip, the students' models are usually of a "V" shaped curve.

All students were able to choose procedures to describe the phenomenon and to propose a model for solution. The largest difficulties in this activity arose from interpreting the data in relationship to a theory. Some groups were still uncomfortable using theories to interpret data and were employing a more empiricist notion of science that did not allow them to understand the nature of the assignment. In general, students understood the Model Map and its connections to the new situations and often explained the new model in relation to the other more well described and understood models. For example, most students were able to extend the Free Fall model to the case of The Jump.

In general, the Model Maps were a useful tool in organizing content in terms of the explicit connections between the models and theories of physics. Students were able to extend their understanding of simple physics models to more complicated phenomena. In addition to content knowledge, the students developed an understanding of the nature of models and theories.

REFERENCES

Ausubel, D. P. (1963). The psychology of meaningful verbal learning. New York: Grune & Stratton.

Brown, D.E. (1993). Refocusing core intuitions: a concretizing role for analogy in conceptual change. Journal of Research in Science Teaching, 30, (10), 1273-1290.

Brown, D.E. & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: abstract transfer versus explanatory model construction. Instructional Science, 18, 237-261.

Chi, M.T.H., Feltovich, P.J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. Cognitive Science, 5, 121-152.

Chi, M.T.H., Glaser, R & Rees, E. (1982). Expertise in problem solving. In R. J. Sternberg (Ed), Advances in the psychology of intelligence, vol. 1 (pp. 7-75). Hillsdale, NJ: Erlbaum.

Chi, M.T.H., Slotta, J.D. & de Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. Learning and Instruction, 4, 27-43.

deJong, T. & Ferguson-Hessler, M.G.M. (1986). Cognitive structures of good and poor novice problem solvers in physics. Journal of Educational Psychology, 78 (4), 279-288.

Ericsson, K.A. & Smith, J. (1991). Prospects and limits of the empirical study of expertise: an introduction. In K.A. Ericsson & J. Smith (Eds) Toward a general theory of expertise (pp. 1-38). New York: Cambridge University Press.

Giere, R.N. (1988). Explaining science: A cognitive approach. Chicago: University of Chicago Press.

Giere, R.N. (1992). Cognitive models of science. Minnesota studies in philosophy of science, Vol XV. Minneapolis, MN: University of Minnesota Press.

Giere, R.N. (1994). The cognitive structure of scientific theories. Philosophy of Science, 61, 276-296.

Glaser, R. (1989). Expertise and learning: How do we think about instructional processes now that we have discovered knowledge structures? In D. Klahr & K. Kotovsky (Eds) Complex information processing: The impact of Herbert A. Simon. (pp.269-282). Hillsdale, NJ: Lawrence Erlbaum Associates.

Halloun, I. (1995). Modelling theory for physics instruction. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Fransico, CA.

Halloun, I. (1996). Schematic modelling for meaningful learning of physics. Journal of Research in Science Teaching, 33 (9), 1019-1041.

Halloun, I. & Hestenes, D. (1985). The initial knowledge state of college physics students. American Journal of Physics, 53, 1043-1055.

Halloun, I. & Hestenes, D. (1987). Modelling instruction in mechanics. American Journal of Physics, 55 (5), 455-462.

Hestenes, D. (1987). Toward a modeling theory of physics instruction. American Journal of Physics, 55 (5), 440-454.

Hestenes, D. (1992). Modelling games in the newtonian world. American Journal of Physics, 60 (8), 732-748.

Klausmeier, H.J. (1990), Conceptualizing. In B.F. Jones & L. Idol (Eds) Dimensions of thinking and cognitive instruction (pp. 93-138). Hillsdale, NJ:Lawrence Erlbaum Associates.

Larkin, J.H. (1981). Enriching formal knowledge: A model for learning to solve problems in physics. In J. R. Anderson (Ed.), Cognitive skills and their acquisition (pp. 311-334). Hillsdale, NJ: Lawrence Erlbaum Associates.

Larkin, J.H. (1983). The role of problem representation in physics. In D. Gentner & A.L. Stevens (Eds.), Mental models (pp. 75-98). Hillsdale, NJ: Lawrence Erlbaum Associates.

Larkin, J.H. (1985). Understanding, problem representations, and skill in physics. In J.W. Segal & R. Glaser (Eds.) Thinking and learning skills (pp. 141-159). Hillsdale, NJ: Lawrence Erlbaum.

Larkin, J.H., McDermott, J., Simon, D.P., & Simon, H.A. (1980a). Models of compentence in solving physics problems. Cognitive Science, 4, 317-345.

Larkin, J.H., McDermott, J., Simon, D.P. & Simon, H.A. (1980b). Expert and novice performers in solving physics problems. Science, 208, 1335-1342.

Marion, J.B. & Thorton, S.T. (1988). Classical dynamics of particles and systems. Third edition. Chicago: Harcourt Brace Jovanovich.

Medin, D.L., & Wattenmaker, W.D. (1984). Category cohesiveness, theories, and cognitive archeology. In U. Neisser (Ed.), Concepts and conceptual development: Ecological factors in categorization (pp. 25-62). New York.: Cambridge University Press.

Murphy, G.L., & Medin, D. L. (1985). The role of theories in conceptual coherence. Psychological Review, 92 (3), 289-316.

Norman, D.A. (1983). Some observations on mental models. In D. Gentner & A.L. Stevens (Eds.), Mental models (pp. 7-14). Hillsdale, NJ: Lawrence Erlbaum Associates.

Robertson, W.C. (1990). Detection of cognitive structure with protocol data: predicting performance on physics transfer problems. Cognitive Science, 14 (2), 253-280.

Rosch, E. (1973). Natural categories. Cognitive Psychology, 4, 328-350.

Rosch, E. (1978). Principles of categorization. In E. Rosch & B.B. Lloyd (Eds), Cognition and categorization (pp. 28-49). Hillsdale, NJ: Lawrence Erlbaum Associates.

Rosch, E,. Mervis, C.B., Gray, W.D., Johnson, D.M., & Boyes-Braem, P. (1976). Basic objects in natural categories. Cognitive Psychology, 8, 382-439.

Saunders, W.L. (1992). The constructivist perspective: Implications and teaching strategies for science. School Science and Mathematics, 92(3), 136-141.

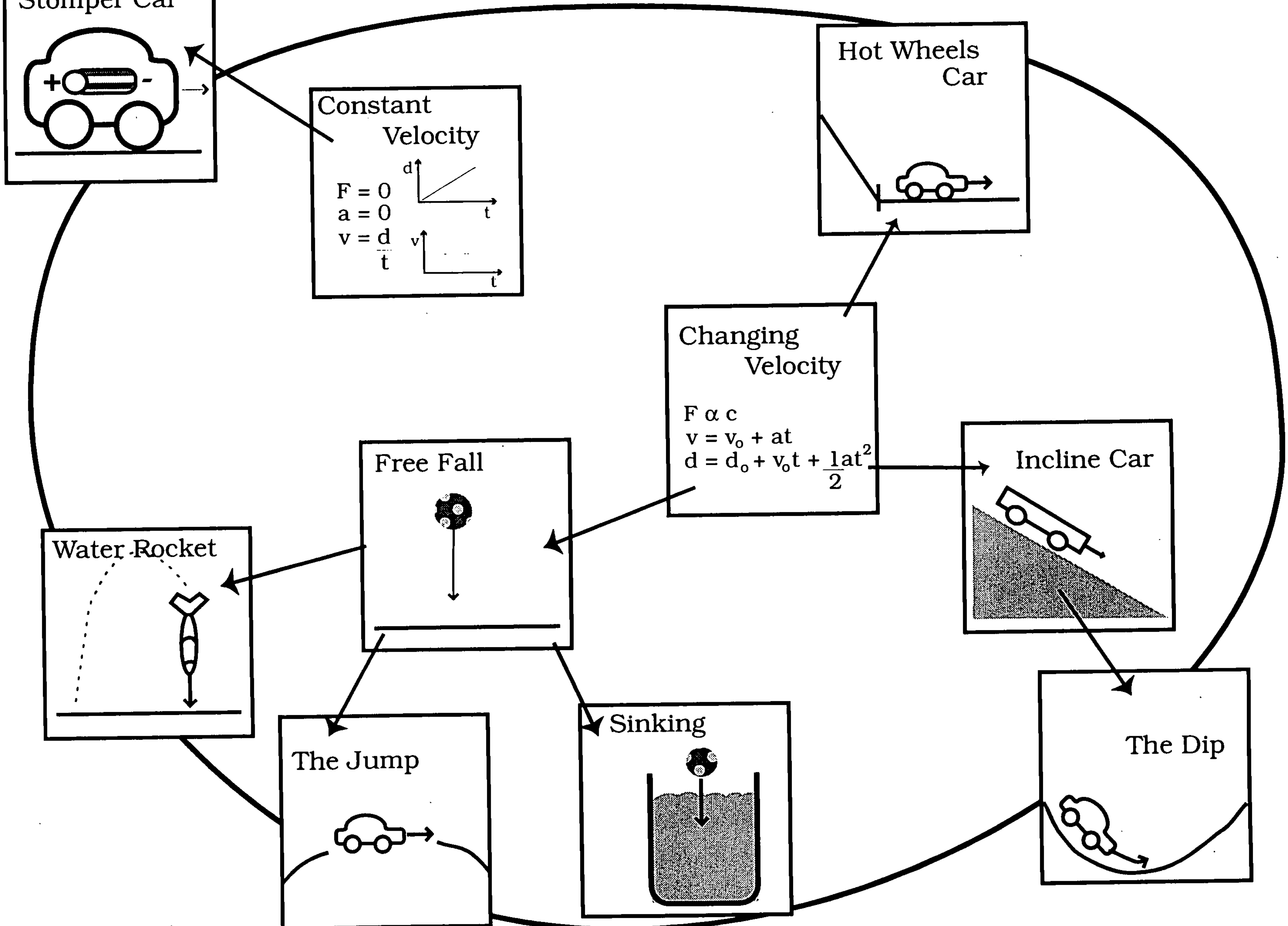
Spalding, T.L. & Murphy, G.L. (1996). Effects of background knowledge on category construction. Journal of Experimental Psychology: Learning, Memory, and Cognition, 22 (2), 525-538.

Veldhuis, G.H. (1990). The use of cluster analysis in categorization of physics problems. Science Education, 74, 105-118.

White, B.Y. (1993). Thinkertools: causal models, conceptual change, and science education. Cognition and Instruction, 10 (1), 1-100.

White, B.Y. & Frederiksen, J.R. (1990). Causal model progressions as a foundations for intelligent learning environments. Artificial Intelligence, 42, 99-157.

Newton's Laws



SE061792

ERIC®

U.S. Department of Education
Office of Educational Research and Improvement (OERI)
National Library of Education (NLE)
Educational Resources Information Center (ERIC)

REPRODUCTION RELEASE

(Specific Document)

I. DOCUMENT IDENTIFICATION:

Title: A Study of Knowledge Structure in Physics

Author(s): Jennifer Discenna

Corporate Source: Western Michigan University

Publication Date:

II. REPRODUCTION RELEASE:

In order to disseminate as widely as possible timely and significant materials of interest to the educational community, documents announced in the monthly abstract journal of the ERIC system, *Resources in Education* (RIE), are usually made available to users in microfiche, reproduced paper copy, and electronic media, and sold through the ERIC Document Reproduction Service (EDRS). Credit is given to the source of each document, and, if reproduction release is granted, one of the following notices is affixed to the document.

If permission is granted to reproduce and disseminate the identified document, please CHECK ONE of the following three options and sign at the bottom of the page.

The sample sticker shown below will be affixed to all Level 1 documents	The sample sticker shown below will be affixed to all Level 2A documents	The sample sticker shown below will be affixed to all Level 2B documents
PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL HAS BEEN GRANTED BY Sample TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) 1	PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN MICROFICHE, AND IN ELECTRONIC MEDIA FOR ERIC COLLECTION SUBSCRIBERS ONLY, HAS BEEN GRANTED BY Sample TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) 2A	PERMISSION TO REPRODUCE AND DISSEMINATE THIS MATERIAL IN MICROFICHE ONLY HAS BEEN GRANTED BY Sample TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC) 2B
Level 1 [X]	Level 2A [ ]	Level 2B [ ]
Check here for Level 1 release, permitting reproduction and dissemination in microfiche or other ERIC archival media (e.g., electronic) *and* paper copy.	Check here for Level 2A release, permitting reproduction and dissemination in microfiche and in electronic media for ERIC archival collection subscribers only	Check here for Level 2B release, permitting reproduction and dissemination in microfiche only

Documents will be processed as indicated provided reproduction quality permits.
If permission to reproduce is granted, but no box is checked, documents will be processed at Level 1.

I hereby grant to the Educational Resources Information Center (ERIC) nonexclusive permission to reproduce and disseminate this document as indicated above. Reproduction from the ERIC microfiche or electronic media by persons other than ERIC employees and its system contractors requires permission from the copyright holder. Exception is made for non-profit reproduction by libraries and other service agencies to satisfy information needs of educators in response to discrete inquiries.

Sign here, → please

Signature: [signature]

Printed Name/Position/Title: Jennifer Discenna

Organization/Address: Dept of Science Studies, Western Michigan Univ. Kalamazoo, MI 49008

Telephone: (616) 387-2715 FAX: (616) 387-4998

E-Mail Address: x93DISCENNA@wmich.edu Date: 5/19/98

(over)

ERIC® **Clearinghouse on Assessment and Evaluation**

University of Maryland
1129 Shriver Laboratory
College Park, MD 20742-5701

Tel: (800) 464-3742
(301) 405-7449
FAX: (301) 405-8134
ericae@ericae.net
http://ericae.net

March 20, 1998

Dear AERA Presenter,

Congratulations on being a presenter at AERA[1]. The ERIC Clearinghouse on Assessment and Evaluation invites you to contribute to the ERIC database by providing us with a printed copy of your presentation.

Abstracts of papers accepted by ERIC appear in *Resources in Education (RIE)* and are announced to over 5,000 organizations. The inclusion of your work makes it readily available to other researchers, provides a permanent archive, and enhances the quality of *RIE*. Abstracts of your contribution will be accessible through the printed and electronic versions of *RIE*. The paper will be available through the microfiche collections that are housed at libraries around the world and through the ERIC Document Reproduction Service.

We are gathering all the papers from the AERA Conference. We will route your paper to the appropriate clearinghouse. You will be notified if your paper meets ERIC's criteria for inclusion in *RIE*: contribution to education, timeliness, relevance, methodology, effectiveness of presentation, and reproduction quality. You can track our processing of your paper at http://ericae.net.

Please sign the Reproduction Release Form on the back of this letter and include it with **two** copies of your paper. The Release Form gives ERIC permission to make and distribute copies of your paper. It does not preclude you from publishing your work. You can drop off the copies of your paper and Reproduction Release Form at the **ERIC booth (424)** or mail to our attention at the address below. Please feel free to copy the form for future or additional submissions.

Mail to: AERA 1998/ERIC Acquisitions
University of Maryland
1129 Shriver Laboratory
College Park, MD 20742

This year ERIC/AE is making a **Searchable Conference Program** available on the AERA web page (http://aera.net). Check it out!

Sincerely,

Lawrence M. Rudner, Ph.D.
Director, ERIC/AE

[1]If you are an AERA chair or discussant, please save this form for future use.

CUA

The Catholic University of America