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USING SIMILARITY RATINGS AND THE PATHFINDER ALGORITHM
FOR EVALUATING STUDENTS' COGNITIVE STRUCTURES
IN NEWTONIAN MECHANICS

DISSERTATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

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* * * * *

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ABSTRACT

Learning involves either the incorporation of new facts into prior knowledge or the modification of the old knowledge structure. Therefore, the construction and organization of structure of a domain knowledge should help the understanding of the student's learning. If the student's cognitive structure in memory can be represented externally, then the instructor can better assess the student's learning difficulty, and remedial instruction can be more effective.

The purpose of this study was to investigate the relationship of high school students' mechanics misconceptions, achievement, and their cognitive structures. Two instruments were used in this study, a Force Concept Inventory (FCI) was administered to test students' misconceptions on mechanics, and a similarity rating task developed by the researcher was used to derive the students' proximity data on mechanics concepts. The sample included high school students (grade 11) in middle Taiwan.
Similarity ratings were transformed into a network (cognitive structure) by the Pathfinder algorithm. Students were divided into three groups according to their performance levels on classroom achievement tests. Three high school teachers were also asked to rate the similarity pairs, and the median of their ratings represents the content/teachers' structure. The data shows that there were more perceived connections among concepts in content/teachers' structure than students', and high achievers' cognitive structures were more similar to that of content/teachers than low achievers. In addition, some similarity pairs were found to have predictive power to students' correct and incorrect responses to FCI items. However, data analyses show no significant difference in cognitive structure between students with and without misconceptions.
To Ya-Ying,
for her love and support
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CHAPTER 1

INTRODUCTION

Overview

Most learning involves either the incorporation of new facts into prior knowledge or the modification of the old knowledge structure (Gonzalvo, Canas, & Bajo, 1994). Many studies show that student knowledge structures change before and after the instruction, and the structures become more similar to that of the instructor after the instruction (Goldsmith, Johnson, & Acton, 1991; Naveh-Benjamin, Mckeachie, Lin, & Tucker, 1986; Shavelson, 1972). Therefore, the construction and organization of structure of a domain knowledge would help the understanding of the student's high-order cognition on that domain (Wilson, 1994). Shavelson (1972) pointed out that the more we know about how to structure a body of knowledge, the better we will be at the development of curriculum and the design of effective instruction.
Students come to school with a view of the world, which differs from those held by scientists. This view is derived from children's own experience of the world. Some researchers call this children's view "misconception" because it departs from conceptions accepted universally. Educators believe that misconception may hinder students' conceptual understanding and quantitative problem solving ability (Clement, 1982). Studies show that students retain their misconceptions even after instruction. Considering the ideas and beliefs that young people bring to their formal study of science is important if these ideas are to be successfully modified by instruction.

Although physics is fundamental to all science subjects and is a requirement for all students who learn physical science, it is usually considered by most students as a difficult subject. According to Clement (1982), there are many sources of the difficulty in physics learning, one of them is the student's misconceptions. Newtonian mechanics is an important, and also, a difficult topic in middle- and high-school physics. It is usually included in the first sections of physics textbooks and is a prerequisite for the physics that follows (Halloun and Hestenes, 1985a). Because of the experiences of daily life, students bring their individual preconceptions of mechanics to the classroom.
Some of these preconceptions are misconceptions that will adversely influence their learning of Newtonian mechanics. The teaching of mechanics is of most concern among all physics topics because mechanics is especially troublesome for many students. Among many variables that may contribute to the student's success in learning physics, content preconceptions is one of the most important variables (Champagne, Klopfer, & Anderson, 1980). When teaching mechanics, teachers need to determine what alternative reasoning processes students use when they are solving problems and what misconceptions influence that reasoning so remediation can be designed for their specific difficulties and be more effective (Bright, 1984).

Learning is a process of building and modification of the learner's cognitive structure. Before the classroom learning, students may have their own cognitive structure about a domain knowledge, some of them are misconceptions—e.g., wrong relationships between concepts. When learning the knowledge in the classroom, students may modify their cognitive structure to make it similar to the structure of the instructor. However, some students may ignore the instruction because new materials are different from their original structure, while some students may just incorporate part of the knowledge into their own structure— to enhance
their misconception by giving justification from the class learning. Their cognitive structures most likely have different inter-relationships from the content structure held by teachers.

In traditional classrooms, teachers may use pre-designed instruments to test all students' understanding of the concepts. However, using the same kind of tests for everyone may not be appropriate because each student has a different knowledge state. Besides, Bright (1984) noted that even very simple concepts or algorithms are built on many other ideas and determining the source of mistakes would be difficult and time-consuming. Moreira and Santos (1981) pointed out that achievement tests in physics are usually concerned with the student's problem-solving ability. However, these tests don't provide any information about the student's cognitive structure, which may help explain his/her ability to solve problems.

If the student's cognitive structure in memory can be represented externally, this would permit the visualization of the relationships among concepts and the instructor might better assess the student's learning.

Pathfinder algorithm, developed by Schvaneveldt and Durso (1981), is a graph-based technique that derives network structure from proximity data. By using a proximity
matrix, the Pathfinder creates a network in which concepts are represented as nodes and relations between concepts represented as links between the nodes. A weight corresponding to the strength of the relationship between two nodes is associated with each link (Gonzalvo et al., 1994).

The Pathfinder algorithm has been used by some researchers in the study of students' cognitive structures and has proven that it can successfully represent cognitive structure. However, almost all studies using Pathfinder have focused on psychology or social science (Durso & Coggins, 1990), so far there is only one study related to physical science—chemical equilibrium (Wilson, 1994). Koubek and Mountjoy (1991) noted different measures of cognitive structure may be appropriate for different domain knowledge. It is needed to determine if Pathfinder is appropriate for physics.

The question of how the students organize their domain knowledge structures differently and their relations with misconceptions and performance is the focus of this study. In the study, the student's cognitive structure related to mechanics will be extracted by a similarity ratings task and the Pathfinder algorithm. The relationship between cognitive structures and misconceptions will be evaluated to
see if students' cognitive structures can be used as predictors of misconceptions.

Statement of Problem

The purpose of this study is to evaluate the validity of similarity ratings and Pathfinder networks for assessing the student's cognitive structure of Newtonian mechanics. Specifically, this study seeks to answer the following questions:

1. What are the high school students' cognitive structures of Newtonian mechanics?

   What are students' cognitive structures of mechanics as represented by Pathfinder network? Are students' structures different from the content/teachers' structure? Studies have shown that students' cognitive structures after instruction are more similar to the content/teachers' structure than before instruction. The difference between students' and the content/teachers' structure suggest that students' learning may be incomplete.

2. Can cognitive structure assessed by the similarity ratings and Pathfinder algorithm be a valid predictor of Newtonian mechanics misconceptions?
Is there a relationship between misconception and cognitive structure? Can we use the cognitive structure measured by similarity ratings and Pathfinder algorithm to predict the existence of misconceptions?

3. Do students that share the same misconception of Newtonian mechanics have similar cognitive structure as measured by similarity ratings and the Pathfinder algorithm?

Learning is the process of creating and revising the learner's cognitive structure (Gonzalvo et al., 1994). The existence of misconceptions may come from the lack of or the incorrect perception of relationships among concepts, or when more important relationships are ignored. This would suggest that students with the same misconception should have some similar characteristics in their cognitive structures (Goldsmith et al., 1991).

4. Do high performance students have cognitive structures related to Newtonian mechanics similar to that of their teachers?

Studies have shown that high achievement students' cognitive structures more nearly parallel the content structure (or the teacher's structure) than that of low achievement students. However, does the student's cognitive structure of Newtonian mechanics as measured by similarity
ratings and the Pathfinder algorithm show this same result? Do similar structures imply similar levels of domain performance?

5. Can the Pathfinder network provide hierarchical information that is contained implicitly in the raw proximity data?

Goldsmith et al. (1991) noted that one of the strengths of Pathfinder is that it can provide hierarchical structures if a hierarchical organization exists in the data. Does this strength generalize to physics content such as Newtonian mechanics?

Assumptions of the Study

For the purpose of this study, the following basic assumptions were made:

1. The data from the individuals' introspection about their knowledge can be used to represent their cognitive structures on that domain knowledge.

2. The concepts selected in the similarity ratings task are a comprehensive set of concepts related to the concept domain.
3. Language translation (English – Chinese) does not alter the meaning of the concepts and their interrelationships.

4. Similarity of concepts as perceived by students can be measured by soliciting their perception of the distance separating the concepts.

Limitations of the study

There are two limiting factors to be considered in the evaluation of this study. The cognitive structures studied are derived from students' responses involving some type of metacognitive judgment. The study is limited by the individuals' ability to reliably introspect about their understanding of a domain of knowledge. In addition, the sample was a convenience sample from a high school in middle Taiwan, how well they are representative of Taiwanese high school students may be questioned.

Definition of Terms

Some terms used in this study are defined here, they are defined constitutively and/or operationally.
Cognitive Structure—

Constitutive Definition: Cognitive structure (knowledge structure) is a hypothetical construct referring to the organization (relationships) of concepts in memory (Shavelson, 1974a). The organized body of knowledge relating to a specific domain that is stored in long-term memory is referred to as the cognitive structure of that domain held by an individual (Ausubel, Novak, & Hanesian, 1978).

Operational Definition: In this study, cognitive structure means the similarity ratings data and networks derived from Pathfinder algorithm.

Concept—

Constitutive Definition: Concept is a symbol or group of symbols that stands for a class or group of objects or events that possess common properties. Concepts can be non-verbal and/or verbal. Concepts are related to one another in complicated ways (Houston, 1981).

Congruent ratings—

Operational Definition: In this study, congruent ratings means the rating values of a similarity
pair rated by teachers are within a maximum range of 2. If a similarity pair has congruent ratings, it means all raters have consistent thinking on the relationship of the concept pair. For example, three teachers rated similarity pair 15 with 1, 2, and 3; it means all teachers agree that a close relationship exits between "action" and "tension". Among all similarity pairs in this study, 61% of them have congruent ratings by teachers.

Content Structure-
Constitutive Definition: Content structure is a web of concepts (words, symbols) and their interrelations in a body of instructional material (Shavelson, 1974b).

Operational Definition: In this study, content structure means the median of teachers' ratings on similarity ratings task of Newtonian mechanics concepts.

Diagnosis-
Constitutive Definition: Diagnosis is used to refer to pedagogical activities aiming to collect and
generate explanations about students and/or their actions (Clancey, 1986).

Misconception-
Constitutive Definition: Misconceptions are naive theories that students bring with them to the science class. These theories stand in marked contrast to what students are expected to learn. (Champagne, Gunstone, & Klopfer, 1983).
Operational Definition: In this study, misconception means the concepts which students have that make their responses to the problems incorrect.

Pathfinder Scaling Algorithm-
Constitutive Definition: The Pathfinder scaling algorithm transforms a proximity matrix into a network structure in which each object is represented by a node in the network and the relatedness between objects is depicted by how closely they are linked (Goldsmith et al., 1991).

Proximity Matrix-
Constitutive Definition: A matrix within which each of its elements represent the degree of closeness.
between two concepts, low value means close or strong relationship and high value means weak relationship or unrelated (Koubek & Mountjoy, 1991).

Operational Definition: In the similarity ratings task, pairs of terms are presented, one pair at a time, to an individual. The individual is prompted to make a distance judgment regarding the conceptual relationship of each pair of concepts. A short distance (which will be transformed to low value) describes that two concepts are psychologically close together. Long distance (large value) means weak relationship. In this study, proximity matrix is the collection of all elements representing the distance between Newtonian mechanics concepts.

Structure-

Constitutive Definition: Structure is an assemblage of identifiable elements and the relationships between those elements (Shavelson, 1974a).

Operational Definition: The structure in this study represents the student's understanding and/or perception of Newtonian mechanics concepts and
their interrelationships as represented by the network from the Pathfinder algorithm.

Summary

The previous studies of cognitive structures on different knowledge domains have shown that students' learning, misconceptions, and problem-solving ability are related to their cognitive structures. If teachers can assess students' learning by their cognitive structures, then the instruction or remediation can be more effective. Since Newtonian mechanics is viewed as one of the difficult and important subjects in science class, there is value in investigating the students' cognitive structures for this concept domain.
CHAPTER 2

REVIEW OF LITERATURE

Introduction

The literature presented in this chapter is organized in two major sections—cognitive structure and misconception. In the first section, the cognitive structure’s definition and its relationship with learning are discussed. Methods of assessing cognitive structures are introduced and some studies on cognitive structures by Pathfinder algorithm are reviewed. In the second section, researches on misconceptions of Newtonian mechanics are reviewed and summarized.

Cognitive Structure

The conception of knowledge organization in memory is based on the schema theory (Jonassen, Beissner, & Yacci, 1993; Kozminsky & Hoz, 1992). Schema theory proposes that knowledge is stored in information packets, or schema, that
comprise learners' mental constructs for ideas. "A schema of a concept (an object or an event) is a knowledge package that represents all the information elements associated by an individual with that concept. Each element can be also a schema, thus forming a complex semantic network" (Kozminsky & Hoz, 1992, P. 76). It is the interrelationships between schemata that give the schema meaning. Each individual possesses a unique schema for objects or events depending on their experiences. Schema theories proposed that schemata are not static; individual's schema changes as the result of acquisition of new knowledge—new elements are added or existing schema elements are modified. In addition, the content of existing schemata and their overall interrelationships influence the rate and the quality of newly acquired information.

Ausubel (1963) defined cognitive structure as "an individual's organization, stability, and clarity of knowledge in a particular subject-matter field at any given time" (p. 26). Ausubel proposed that cognitive structure is the major factor influencing the learning and retention of meaning of new material. A meaningful learning occurs when the learner relates the new material nonarbitrarily and substantively to his/her cognitive structure (Ausubel et al., 1978).
Shavelson (1974a) explained the cognitive structure from the viewpoint of information processing. The information processing model can be divided into two general components: perception and memory. Perception includes the transfer of physical signal into sensory image, the extraction of relevant characteristics from the image, and the association of these characteristics with a previous learned structure. Memory is the second component of the model. Memory includes those psychological processes which serve to retain information received by an individual (Shavelson & Stanton, 1975). Memory consists of four subcomponents: short-term memory (STM), working memory (WM), long-term memory (LTM) and a retrieval and decision process (Shavelson, 1974a). The last two subcomponents serve to define the cognitive structure. There are three important characteristics attached to the network: (1) a relational structure that nodes are linked by specific types of relations; (2) a hierarchical feature that one node may represent a set of nodes (concepts); and (3) a structure of implicit information.

The meaning of a concept in a network is determined by a list of its properties, which in turn are other concepts (nodes). A concept is a cluster of relations among other concepts. Similar concepts may have many properties
(concepts) in common. Nodes (concepts) are connected by links (relationships). Shavelson (1974a) classified relationships between concepts as: (1) superset- e.g., flowers may be roses; (2) subset- e.g., rose is a flower; (3) attribute- e.g., one attribute of rose is fragrance; (4) part- e.g., flower is a part of plant; (5) similarity- e.g., a horse is like a pony; (6) proximity- flower is grown/seen in nursery; (7) antecedent-consequent- e.g., change of gas temperature may cause change in volume; (8) operations- e.g., force equals mass times acceleration.

Koubek and Mountjoy (1991) pointed out that the nodes in a cognitive structure may either be declarative or procedural, and they can exist at different levels of abstraction. The strength of relationships between nodes may vary in degree, and there may be more than one type of relationship between two nodes.

According to cognitive psychologists, an important component of the knowledge base is declarative knowledge. Declarative knowledge is the domain-specific, factual content residing in long-term memory. Declarative knowledge is often represented as semantic networks consisting of concepts (nodes), and links representing meaningful connections between concepts (Gomez & Housner, 1992). In order to be knowledgeable in a domain knowledge, one must
understand the interrelations among the important concepts in that domain (Johnson, Goldsmith, & Teague, 1994).

In a study of university students' problem solving ability, Zajchowski and Martin (1993) examined the differences of knowledge, strategies, and knowledge structure between stronger and weaker problem solvers when they solved physics problems. The researchers concluded that the difference in knowledge application appears to be mainly dependent on the difference in knowledge organization. Gonzalvo et al. (1994) noted that experts' cognitive structures are more organized and clearly structured around a few central concepts, whereas novices' structures show less organization.

Cognitive Structure and Learning

Shavelson (1974a) noted that the structure of a subject starts in the minds of the "great scientists", this structure is communicated to the teacher through scientists' writings and other channels. The teacher, then, communicates the subject-matter structure to the student through verbal exposition and textbook. Therefore, instruction is viewed as the communication of a knowledge structure from the teacher (or textbook) to the student.
(Goldsmith & Johnson, 1990). The goal of instruction, then, is to convey an accurate representation of a subject-matter structure to the students (Shavelson, 1974a).

According to constructivism, learners respond to their sensory experience by "building or constructing in their minds, schema or cognitive structure which constitutes the meaning and understanding of their world" (Saunders, 1992, P. 136). Individuals attempt to make sense of a new phenomenon which they encounter by the establishment of structure in their memory. According to the constructivist's perspective (Saunders, 1992), meaning is created in the mind of the student as a result of the student's sensory interaction with his/her world. When encountering a new situation, the student tries to explain or predict by his/her cognitive structure from past experience. The student's structure is confirmed and held more strongly if the prediction or explanation is confirmed by the experience. However, the prediction or explanation might be considered wrong if it doesn't agree with that accepted by scientists. Under this situation, the student may have several options to resolve the conflict (Saunders, 1992). The student may just reject the sensory data by ignoring its existence, or claiming that it's invalid, or
just disengaging himself/herself cognitively, and cling to his/her cognitive structure.

Champagne et al. (1980) pointed out that cognitive structures are highly resistant to change even though they are contrary to observational evidence or formal classroom instruction. On the other hand, the student may believe the data and revise the cognitive structure so the prediction or explanations are more consistent with what is observed. Then it is said that meaningful learning occurs. Learning is an individual constructive activity through which new material is related to what is already known. It leads to an end product which is different for each person (McClelland, 1982). Ausubel et al. (1978) suggests that learning will be meaningful only when new concepts can be consciously related to relevant concepts which have been acquired previously. For meaningful learning to occur the student must be able to integrate new concepts into his/her cognitive structure (Summers, 1982).

Cognitive structure is the individual's representation of his/her sensory experience. Therefore, it is likely to be influenced by the organization of the content when it is taught. In a study of the student's cognitive structure in thermodynamics (Moreira & Santos, 1981), two groups of students were taught by different approaches: Traditional
and Ausubelian approach. In the traditional approach, the content instructed was arranged according to the order of the textbook. In the Ausubelian approach, on the other hand, the content was arranged hierarchically according to Ausubel's learning theory, the most inclusive (general) concepts were presented earlier. The study showed that the cognitive structures of the students in the Ausubelian approach group were more coherent with the basic laws and the conceptual structure of the subject.

When the student engages in the study of a domain knowledge, he/she begins with little or no structure related to the knowledge. The student builds complex structure gradually as learning progresses and the resulting structure resembles the instructor's.

In a study of students' physical education teaching methods knowledge, Gomez and Housner (1992) found that the students' knowledge was more coherent and corresponded more closely to the instructor's following the course. The learning itself can be viewed as a process of building and refining cognitive structure.

In a study of cognitive structure of Newtonian mechanics, Shavelson (1972) concluded that the students' achievement increased and cognitive structures were closely related to the content structure after instruction. The key
concepts in Newtonian mechanics were interrelated more closely at the end of instruction than at the beginning.

In a study of 8th graders' geology knowledge, Champagne, Klopfer, Desena and Squires (1981) found that the students' knowledge representations became more congruent with the content structure of the instructional materials after instruction, the researchers proposed that the change of structure provides concrete evidence of students' growth of knowledge and their ability to structure knowledge.

Wilson (1994) proposed that the lower achievers need to experience notable knowledge restructuring and reorganization because of a lack of multilevel structures and links between concepts. He stated that the explicit teaching of specific strategies will help the construction of complex and hierarchical knowledge structures.

Chi and Koeske (1982) noted that the difference of memory performance lies in the particular configuration of nodes and links; the children with better knowledge structures have better memory performance.

When assessing students' learning, traditionally, evaluation is done by presenting various recognition (e.g., true-false or multiple choice) or recall (e.g., essay) types of questions that are directly related to the domain knowledge. However, Goldsmith and Johnson (1990) pointed
out that this type of assessment has several potential problems: (1) the performance on these types of questions may be handicapped by retrieval problems, because conventional tests depend heavily on episodic memory; knowledge retrieval processes are influenced by the context specific cues of the questions. (2) Much of the knowledge (e.g., procedural knowledge) that teachers expect students to learn is implicit knowledge that is difficult to state explicitly. This is difficult to assess with direct questions. (3) The development of objective and easy scoring tests that can assess more abstract or conceptual aspects of knowledge is another concern. It requires considerable expertise to develop multiple choice exams, which are objective and easy to score, to assess conceptual knowledge. On the other hand, essay questions can assess conceptual knowledge more readily; however, the scoring is difficult and time-consuming. In a study of assessing college students' classroom knowledge on psychological research techniques, Goldsmith and Johnson (1990) used similarity ratings to assess students' cognitive structures; they concluded that the knowledge representations based on the students' concept ratings do indeed provide a valid assessment of their classroom learning.
In a study of university students' problem-solving ability in physics (electricity and magnetism), Jong and Ferguson-Hessler (1978) found that mere presence of knowledge in memory doesn't imply that the knowledge can be used for problem solving; a suitable cognitive structure plays an important role in problem solving. They noted that good novice problem solvers have their knowledge organized in a more problem-type-center way than students with poor performance.

Jonassen (1987) claimed that we first need to be able to describe individuals' cognitive structure in a meaningful and feasible way so the instructor can assess changes in cognitive structure and mediate those changes (that is, learning). Shavelson (1972) proposed that in order to teach effectively, in the process of development of curriculum and formulation of instruction, teachers must consider how the students structure the body of knowledge.

Measurement of Cognitive Structure

The goal of measurement of cognitive structure is to retrieve the student's representation of a subject-matter structure from his/her cognitive structure. There is no way of knowing whether or not structural knowledge has been
successfully communicated to the student without the evaluation of cognitive structure (Diekhoff, 1983).

Shavelson (1974a) claimed that a measurement method should have the ability to reveal (1) the property lists that give meaning to individual concepts, and/or (2) the overlap of property lists associated with pairs of concepts, and/or (3) the various relationships between pairs of concepts, and/or (4) the decision strategy used in selecting or evaluating concepts in LTM.

Although some theorists argue that an individual's knowledge can be measured only by self-report methods (Shavelson & Stanton, 1975), Cooke (1990) noted that it is difficult to verbalize personal knowledge. Verbal reports are often inaccurate and incomplete. Besides, they provide no information regarding the organization of knowledge. Essay examinations, which ask students to discuss the relationships between concepts, are perhaps the most conventional method of assessing knowledge structure. However, Diekhoff (1983) and Gonzalvo et al. (1994) noted that this method is quite limited because there are many other factors, in addition to the student's structure knowledge, which may influence the test scores. Goldsmith et al. (1991) criticized that because essay questions allow
a wide variety of responses, it would be extremely difficult to derive the structural relationship of all concepts.

Naveh-Benjamin et al. (1986) claimed that conventional achievement tests measure bits of knowledge but are inadequate measures of students' cognitive structure. A structural approach for assessing cognitive structure is comprised of three distinct steps: (1) knowledge elicitation, (2) knowledge representation, and (3) evaluation of an individual's knowledge representation (Goldsmith et al., 1991).

Methods of Assessing Cognitive Structure

All knowledge elicitation methods start first with individuals making some type of metacognitive judgment (Koubek & Mountjoy, 1991), which is fundamentally introspective in nature. These types of techniques are quite subjective because it is known that individuals are unable to reliably introspect about their cognitive processes. However, Koubek and Mountjoy (1991) claimed that this type of information source should not be ignored because "metacognitive judgments can contain information that is difficult or impossible to obtain from objective sources" (P. 11). Knowledge elicitation measures an
individual's understanding of relationships among a set of concepts. Many methods have been used for knowledge elicitation, e.g., word association proximities, similarity ratings, card sorts, tree construction, graph-construction method, pattern notes, order tree techniques (Jonassen et al., 1993; Koubek & Mountjoy, 1991; Shavelson, 1974a, 1974b; Jonassen, 1987; Naveh-Benjamin et al., 1986).

The second step of measurement is to represent the elicited knowledge as a structure, which can be assessed through some scaling procedure in the third step. Although the data from the first step can be thought of as a representation of domain knowledge, these raw data are usually assumed to be "noisy" and there is difficulty in reflecting the underlying organization of the data (Goldsmith et al., 1991). Several methods, like Pathfinder and multi-dimensional scaling (MDS), had been developed to transform the raw data into a well-organized structure. The third step is to evaluate the individual structure by comparing it with a standard, such as the knowledge structure of an expert or teacher.

Koubek and Mountjoy (1991) noted that three characteristics are related to the type of knowledge elicited by these techniques: (1) the knowledge elicited is relatively stable over time, (2) the knowledge elicited
tends to be more declarative than procedural in nature, and (3) different techniques may be more appropriate for some specific domains.

**Similarity Ratings**

Similarity rating is one of the most direct methods of detecting the relationships between concepts in a personal cognitive structure. In this technique, the individual makes judgments regarding the relationship between concept pairs, one pair at a time. The technique is based on the hypothesis that "given an individual's judgment or rating of the conceptual similarity of (or distance between) two concepts, this rating is related to the psychological distance between the two concepts in people's memory" (Koubek & Mountjoy, 1991, p. 24). Rumelhart and Norman (1988) noted that two concepts are similar if their underlying features are similar or overlay. If each concept is represented by N features, the concept can be viewed as a point in an N dimensional space where each dimension represents a feature. In this type of model, "similarity is often assumed to be a monotonically decreasing function of the distance between points in multidimensional space" (Rumelhart & Norman, 1988, p. 518). In a similarity ratings
task, a set of related concepts are identified and arranged by pairs, then the respondents are asked to rate the degree of similarity or dissimilarity for all pairs of concepts. The judgment most often takes the form of a rating on a numeric scale (e.g., 1-7, 1-9). Constructs in an individual's cognitive structure are differently related, some are closely related while others may be loosely related (Jonassen et al., 1993). In the spatial metaphor, more closely related concepts appear closer in geometric space while dissimilar concepts are further apart. The similarity ratings method is the simplest way for identifying those distances. It assumes the geometric distances between concepts in n-dimensional space represents the psychological proximity of the concepts in the individual's cognitive structure (Jonassen et al., 1993). When conducting a similarity rating study, the first task is to select concepts from the content subject. These concepts must be roughly of equal importance and should be the most important concepts in the domain. A matrix is constructed in which all possible pairs of concepts are represented. The subjects are asked to rate the strength of the relationship between each pair on a numeric scale, where the smallest number indicates little or no relationship between two concepts and the largest number indicates a very strong
relationship between two concepts. The resulting ratings are then converted into a distance matrix by subtracting the given rating from the maximum rating (Koubek & Mountjoy, 1991).

Although similarity rating is criticized as quite subjective, researchers have found that subjects show good reliability in their judgments over time (Diekhoff & Wigginton, 1982). In a comparison study, Diekhoff (1983) used three testing methods, a multi-choice test, essay test, and a relationship judgments test, to examine the cognitive structures of undergraduate general psychology students. The results showed that relationship judgment tests provided a valid means of assessing knowledge of both individual concepts and structural knowledge.

Pathfinder Networks

Pathfinder networks are configurations in which concepts (objects, events, actions, or entities) are represented as nodes and relationships are represented as links connecting the nodes. The links are assigned a weight that reflects the strength of the relationship between the concepts in terms of the distance between nodes (Dearholt & Schvaneveldt, 1990).
Pathfinder networks are derived from proximity matrix data. Each concept in the matrix is represented as a node and the proximities (weight) represent how closely the nodes are linked. Not every node in the network is necessarily linked to every other node. A link between two nodes is added if distance (weight) of this direct link is less than the distance of all possible indirect paths between these two nodes (Branaghan, 1990). Therefore, "Pathfinder extracts the latent structure in the data" (Jonassen et al., 1993, p. 73), and is good for comparing local or pairwise concepts in a knowledge domain. An example of similarity matrix and Pathfinder network is provided in Appendix D. Koubek and Mountjoy (1991) concluded that Pathfinder is a useful technique in revealing differences in the levels of abstraction between different experience groups.

Developing Pathfinder networks begins with a matrix of similarity ratings; a series of computer programs can be used to transform similarity data into Pathfinder networks.

Pathfinder provides two measures of correspondence that are used to compare cognitive structures: 1) graph-theoretic distance (GTD) and 2) similarity (Closeness) (Gomez & Housner, 1992). Graph-theoretic distance (GTD) is a measure of correspondence computed by correlating graph-theoretic distance between every pair of nodes in two Pathfinder
networks. A Closeness \((C)\) value measures the degree to which the same node in two networks is surrounded by a similar set of nodes. The \(C\) (Closeness) measure is a set-theoretic method of quantifying the configural similarity between two networks having a common set of nodes. The comparison is based on each node in the two networks and the results are averaged to represent an overall index of network similarity (Goldsmith et al., 1991). See Appendix A for a description of Closeness measure.

Gomez and Housner (1992) claimed that the advantage of a Pathfinder network over the original proximity data is that "it results in a reduction to the most salient relationships among concepts, and provides a visual summary of those relationships" (p. 7).

In a study of college students' similarity ratings on introductory psychology, Roske-Hofstrand and Paap (1990) concluded that students made very fine distinctions among pairs of highly related concepts, but discriminability suffers for the unrelated pairs.

Branaghan (1990) pointed out that subjects usually have no trouble determining strong relationships between concepts. On the contrary, they are often uncomfortable assessing unrelated items, it is difficult to give a number to this unrelatedness- it makes no sense to give a number to
the degree of unrelatedness. For example, a student may give a number of 4, 5, or 6 (in a scale of 1-7) to represent the relation between cat and tiger, but it may not be clear how he/she should rate the relationship between cat and bird? It is questionable to differentiate ratings of 1 and 2. Therefore, ratings for strong related pairs contain more meaningful information. Pathfinder defines a network that includes important links (which means high related relationship) as indicated by the proximity data (Branaghan, 1990).

Pathfinder network representations reflect more local information (i.e., to the level of specifying which concepts are directly linked) (Johnson et al., 1994). By checking the links among specific nodes, the relation of structure and some specific misconception (or performance) may be found.

Goldsmith et al. (1991) noted that one of the strengths of Pathfinder is that it does not enforce hierarchical solution; however, hierarchical networks may be produced if a hierarchical organization exists in the data.
Goldsmith et al. (1991) assessed the cognitive structure of college students on psychological research techniques by Pathfinder and other methods. By comparing the cognitive structures derived by Pathfinder and multidimensional scaling (MDS), they found that Pathfinder network was a better predictor of the student's performance. They also found that better students do indeed have more similar structure with each other, while poor students had less similar structure with each other. Their findings indicated that students' representations of domain knowledge following the instruction corresponded more closely with that of the teacher's. They concluded that novice students have no particular structure before their learning and the structure is organized gradually in the process of learning.

Gonzalvo et al. (1994) used Pathfinder techniques and multidimensional scaling (MDS) to assess the changes of the cognitive structure of college students' psychology knowledge before and after instruction. The results showed that the acquisition of knowledge implies the modification of cognitive structure. Experts' structures were more organized, and structured around a few central concepts,
whereas the student's structure showed less presence of organizational principles and central concepts. In addition, the researchers concluded that the Pathfinder technique provides more local concept-to-concept structure information. Therefore, it enables the assessment of an individual's understanding of individual concepts by comparing the student's and experts' similarities in the network connections to individual concepts. It can also show the local connections changed as a function of learning.

Gomez and Housner (1992) studied the structure for undergraduate students enrolled in a teaching methods course by Pathfinder algorithm. By comparing the students' knowledge of key pedagogical concepts with the instructor's, this study showed that the students' knowledge was more coherent and corresponded more closely to the instructor's after the instruction. The results also showed that the final measures of coherence and correspondence were significantly related to course performance.

In a study of cognitive structure of year-12 students' chemical equilibrium concepts, Wilson (1994) used data from concept mapping and multidimensional scaling (MDS), instead of direct similarity ratings, as the input of the Pathfinder algorithm. The subjects were asked to draw a concept map
representing the understanding of chemical equilibrium. The concept map was then transformed by MDS to cell matrix, indicating the presence or absence of a link between concepts in the concept map. Then proximity matrix was calculated by binary matching coefficient DICE and used as input to the Pathfinder algorithm. The results showed that the high achievers' cognitive structures were more similar to each other than to the low achievers. These two groups also showed differences in the degree of hierarchical organization of knowledge, and these differences influenced their achievement and relative expertise.

Kokoski and Housner (1994) used Pathfinder technique to examine the cognitive structure of three teacher educators and their students in teaching methodology classes. They found that, for two of the three teachers' classes, the student's cognitive structures corresponded more closely with the instructor's after the instruction than before. Moreover, those who performed better in the classes had structures that corresponded most to that of the teacher educators.
Importance of Misconception Diagnosis

Many studies demonstrate that, in many science content areas, people have descriptive and explanatory systems for scientific phenomena that were developed before they began their formal study of science (Champagne et al., 1983). These descriptive and explanatory systems differ significantly from scientific viewpoints. These systems show remarkable consistency across different populations, age, ability, or nationality and they are remarkably resistant to change in the traditional setting.

Some researchers call them "misconception" because they depart from those conceptions accepted universally by scientists (McClelland, 1985; Terry, Jones, & Hurford, 1985). Some researchers, however, assert that these students' conceptions should be respected as creative constructions of the individual, as they try to understand and deal with the world around them. Their ideas should be considered as alternatives to established concepts (Andersson, 1986). Now most researchers are inclined to use neutral expressions to refer to them, for example, "naive conception" (Champagne et al., 1983), "common sense" (Halloun & Hestenes, 1985b), "preconception" (Clement, 1982), "student ideas" (Kuiper, 1994), "prior knowledge"
(Sutton, 1980), "alternative framework," "children's ideas" (Clough & Driver, 1985), "student view" (Thornton, 1994), "students' reasoning" (Viennot, 1985; Twigger et al., 1994). However, the term "misconception" will be used in this study because it refers to the student's ideas, which the diagnostic system wants to find, that are incompatible with scientific knowledge instructed by the teacher.

Many students have difficulties in learning science at different school levels. Some of these difficulties come from students' prior knowledge about the physical world (Champagne et al., 1983; Clement, 1982; Reif & Larkin, 1991). If teachers can diagnose what a child already knows (prior knowledge), then teachers can examine teaching methods to determine if they can be modified to overcome the students' problems (Birenbaum, Kelly, & Tatsuoka, 1993; Sutton, 1980). Bright (1984) claimed that, only after a correct diagnosis has been done, can remediation be focused on precise problems to make the remedial instruction more effective than general remediation on a broad range of possible difficulties. Without careful diagnosis, remediation may be misdirected and ineffective (Bright, 1984).

Sutton (1980) pointed out that reliable techniques are needed to find a person's ideas and represent them on paper.
He reviewed several techniques that have been used in probing the learner's structure of ideas: Clinical interview, word association, writing or choosing a definition, and identifying and using bipolar dimensions in a "semantic space." The clinical interview is the most popular and effective method among them. The interviewer starts with open questions and accepts all answers. This method does give the interviewee a greater chance to explain his/her reasoning. However, the interview process takes a long time and the interpretation of interview data is difficult.

Browning and Lehman (1988) listed some methods used in the studies of misconception: audiotaped structured interviews, videotaped problem solving, essay questions, and "think-aloud" techniques. Although these techniques are effective, Browning and Lehman (1988) commented that they are difficult and time-consuming in practice.

Although the traditional ways of assessing student reasoning are useful, they are usually time consuming. Moreover, very often teachers are unable to draw out a suitable state of the student's knowledge. Janke and Pilkey (1985) pointed out that diagnosing errors is a laborious task that the teacher may lack sufficient training or time to do. Bright (1984) proposed that the delay caused by
paper/pencil diagnostic tests and the necessity of careful interpretation of students' answers make the test unattractive to the teacher. Although interviews can discover the insight of students' problems, it is more time-consuming and the teacher may lack the training to carry out the interview.

In recent years, many studies have been carried out to identify, analyze, and understand students' preconceptions. Research subjects range extensively from kindergarten children to college students, but most are elementary and middle school students. Among all science courses, physics is the most well-researched topic. For example, density and mass (Hewson, 1986), forces on moving objects (Clement, 1982), pressure in fluid and atmospheric pressure (Clough & Driver, 1986), the law of reflection (Mohapatra, 1988), conservation of energy (Solomon, 1985), and conduction of heat (Clough & Driver, 1985).

There are over 1000 research reports addressing the issue of students' understanding of science concepts (Wandersee, Mintzes, & Novak, 1994). Among these studies, about two-thirds study physics, and almost half of those focus on mechanics.

The first topic in almost all levels of physics textbooks is concerned mainly with Newtonian mechanics, and
mechanics is an essential prerequisite for most of the rest of physics. Therefore, the student's prior conception of mechanics is most important to his learning physics (Halloun & Hestenes, 1985a, 1985b). The resistance of prior conception to change is also particularly striking on mechanics (Champagne et al., 1983).

Analysis of students' prior concepts can help teachers understand what the students bring into the classroom, and the difficulties students may have when learning scientific concepts, therefore, enabling more effective instruction in the classroom (Osborne & Gilbert, 1980).

Studies on the Misconception of Mechanics

Brown (1989) carried out a study to understand high-school students' misconceptions related to Newton's third law. This paper reports on three kinds of data: (a) interviews involving oral tutoring, (b) interviews involving tutoring with written materials, and (c) a multiple-choice diagnostic test.

The subjects of the first study are five high-school students who had not yet taken physics. In the second study, the subjects are 21 pre-physics high-school students who were given a written explanation of the third law. The
sample responding to the multiple-choice diagnostic test included seven physics classes in two high schools. The tests include a pre-test administered before students began to learn physics and a post-test administered after all instruction in mechanics had been completed.

In the oral tutoring study, every student believed that when a moving cue ball collides with a stationary billiard ball, the moving cue ball 'had' more force and thus exerted a greater force than the stationary billiard ball. In the interview study involving tutoring with written materials, students had learned a full page explanation of Newton's law with many examples from daily experience. When given the problem: a 200 pound steel block (block A) rests on top of a 40 pound steel block (block B), what are the forces between them, all students said A and B exert a force on each other, but believed that A exerted a greater force than B did. It seems none of the students referred to the third law.

In the multiple-choice diagnostic test (Brown & Clement, 1987), 23% of the thirteen third law questions were answered correctly on the pre-test and 44% on the post-test. In this study, it appeared that most students believed force to be an innate or acquired property of objects. For example, in the steel blocks question, 78% of students incorrectly answered the question and 88% of them thought
force is a property of objects, 40% of them answered incorrectly in the post-test and 82% of them still thought force is an innate property of objects. In another question related to bowling, students were asked to compare the forces when a bowling ball (16 lb.) hits a bowling pin (4 lb.), 99% of the students answered it incorrectly in the pre-test. All of them thought the bowling ball exerted more force than the bowling pin, 94% of the students still gave wrong answers on the post-test and 99% of them remained with the same conceptions that they had in the pre-test.

Most students in this study had the misconception that force is an innate or acquired property, which is contrary to the viewpoint of Newtonian mechanics that forces arise from interactions between objects. This study also showed that traditional instruction does not seem to change students' misconceptions.

By using written tests and video-taped problem-solving interviews, Clement (1982) summarized the first year engineering students' preconception of "motion implies a force" as:

1) Continuing motion (constant or changing velocity) means there is a force acting on the object in the direction of motion.
2) The force is greater than the opposing force if the moving object continues in the face of an obvious opposing force.

3) The force's "dying out" or "building up" accounts for the changes in an object's speed.

Halloun and Hestenes' (1985a; 1985b) used a multiple-choice mechanics diagnostic test and interviews to survey the concepts about motion held by college students enrolled in physics courses. The researchers found that many students had the Aristotelian and impetus views of motion, which were apart from Newtonian concepts. Their misconceptions about force were:

1) In the absence of forces, every object remains at rest (with respect to the earth).

2) Motion is sustained by continuous action of an external force (or gravity) or an internal force (impetus) in the object.

3) The greater mass exerts the greater force.

4) The object that causes motion of another exerts the greater force, because it overcomes the other's opposition.

From a written test given to secondary school students of two countries and students at (pre-)university science courses, Kuiper (1994) found that many students used two
main types of incorrect ideas: intuitive idea- concepts students had prior to secondary education, and intermediate idea- concepts with some influence of education, yet not correct. The researcher claimed that if students have an alternative framework, then certainly the same problems should be answered with the same student ideas even though these problems are presented in different context. There are four different types of problems in the test. In the problems involving collisions, the intuitive view answer is that only a moving ball exerts a force while the intermediate view answer is that there are two unequal forces against each other. When asked to identify the forces on launched objects, students with an intuitive view responded that only impetus force acts on the object in the direction of motion while students with an intermediate view responded that there are two forces- impetus force and gravity (and air friction) acting on the object. In the problem of rest situation, the intuitive view answer is "no force acts on the object" while the intermediate view answer is "only gravity acts on the object at rest." In the moving system problems, the intuitive view proposed that an object released from a moving system falls down due to gravity while the intermediate view proposed that apart from impetus force, there is force(s) not in the direction of motion.
Kuiper (1994) concluded that force was seen as a kind of panacea by the student; it can be used to explain whatever phenomenon: A force can either keep an object at rest, set it in motion, keep it in uniform motion, or stop its motion.

McDermott (1984) reviewed research on conceptual understanding in Newton mechanics and classified the results by topics in mechanics: passive force, gravitational force, velocity and acceleration, force and motion, and a few other concepts in dynamics. These misconceptions are described here:

1) Passive force: Most students ignore the existence of "passive force," which means a force that adjusts itself in magnitude in response to an applied force, e.g., the tension exists in a string when it is stretched by an external force, a table or chair exerts a force upwards when something is placed on it even if there is no motion.

2) Gravitational force: Many students believe that the block's speed in the free fall is roughly proportional to the gravitational force, and the time of fall is shorter for the heavier block. Some students still reach correct conclusions, e.g., the force depends on the mass, even though they also believe incorrectly that the time of
fall depends on the mass. In another study, a bucket of sand was hung on one side of a pulley and a block of wood of equal mass on the other side. The bucket was placed higher than the block. When asked to compare the weights of the two objects, many students thought that the one closer to the earth is heavier.

3) Force and motion: Many students believe that a force is always necessary to sustain motion, even though the velocity is constant.

In a study of students' concept of forces and equilibrium, Terry et al. (1985) presented a diagram of a box resting on a table to three groups of students of different years, and asked their explanations about what keeps the box at rest on the table and if it was necessary for the table to exert a force on the box. The first group only learned the concept of force in an integrated science course; almost all of them could only identify one force acting on the box—gravity and thought that it was not necessary for the table to exert a force on the box. The second group had been instructed on the first law and had some experience with the second law. More than two-thirds of them still didn't have the correct concept. In the third group, more than half of the children could not explain
correctly the forces in the static equilibrium case even though they had learned all of Newton's three laws.

Twigger et al. (1994) conducted an interview study with students from age 10-15 to identify the student's reasoning about motion and force. Five types of motions were studied in the review. These motions included: motion on the horizontal as a result of an impulsive force, constant motion on the horizontal with friction, accelerated motion on the horizontal, free-fall motion, and projectile motion. The researchers summarized a number of students' conceptions of force and motion:

1) A moving object stops because the push (applied force) is used up.

2) All students recognize that a constant applied force is necessary to maintain an object's motion. However, nearly all say that the applied force must be greater than the resistance, and the object would stop if they were equal.

3) A steadily increasing force is needed to make an object move with acceleration. A constant force is needed to maintain a constant motion.

4) A projectile's downward motion is faster than upward motion. The push getting used up when the object goes
up and then gravity controls the motion, the object falls down.

From an educational perspective, it is necessary to consider the concepts and beliefs that young people bring to their formal study of science, if these ideas are to be successfully modified by instruction (Clough & Driver, 1986). The research about misconceptions should not just be concerned with itself but also needs to consider how to promote conceptual change in classrooms.

Summary

Relevant studies on cognitive structures of different domains has supported the importance of further study on cognitive structures. Through the help of students' cognitive structures, the teachers can better understand the students' learning problems.

The review of misconceptions studies shows that the same misconceptions are shared by students of different levels. Many students have substantial difficulties in learning science; misconception is one of the most important reasons (Reif & Larkin, 1991). If the teacher can diagnose what the misconceptions are, then instructions can be
figured out to enhance science learning. Reliable
techniques for finding out about a student's knowledge state
are critical.

For most students and teachers, achievement testing in
the classroom is synonymous to the evaluation of learning.
Although this kind of evaluation will continue to be
essential in the classroom, Novak and Gowin (1984) proposed
that a much wider range of practicable valuation methods are
needed. Assessment of cognitive structure may play a role
in the evaluation of students' learning.
CHAPTER 3

METHODOLOGY

Research Design and Strategies

This study was organized in five stages. In the first stage, a list of concepts on Newtonian mechanics were selected from textbooks. They included general concepts (e.g., first law, force) and some specific concepts (e.g., tension). These concepts were arranged by pairs in a random order and used as an instrument for similarity ratings. These pairs were tested in a pilot study and concept pairs were modified for formal study.

In the second stage, subjects were asked to rate how closely the concepts are related for every possible pair of concepts by indicating the distance separating the concepts for each pair. In addition, subjects were asked to describe in writing the relationships of some concept pairs. At the same time, three experienced teachers were asked to complete
the same task and their data were used to represent the content structure of the domain knowledge.

In the third stage, a multi-choice misconception diagnostic test- Force Concept Inventory (FCI, see Instrumentation section and appendix B) were administered to students. The result were analyzed to identify each student's misconceptions.

In the fourth stage, the Pathfinder scaling algorithm was used to transform the relatedness data into associated network representations. A computer program (Knowledge Network Organizing Tool, KNOT, developed by Interlink, Inc.) was used to do the transformation. Each concept was represented by a node and relations between concepts are represented by links between nodes. Through this process, Pathfinder algorithm transformed proximity data into networks comprised of the most important relationships among concepts.

In the last stage, the results (misconceptions) from the diagnostic test (FCI) were compared with cognitive structure (Pathfinder network) to see the relationships. In addition, the sample was divided into three groups according to rank of achievement scores (from students' performance records on classroom test, which was prepared by their teachers, right after the instruction of Newtonian
mechanics), the top 27% of the sample represented the high performer group and the lowest 27% represented the low performer group. Their relationship to the content/teachers’ structure were examined for differences and patterns.

Stage I: Preparation of concept list

A list of Newtonian mechanics concepts for similarity ratings were selected first by the researcher; they were arranged by pairs and administered to a small group of students in a pilot study. After the pilot test, a group discussion among students and the researcher was held to help modify the concept list. An experienced high school teacher was asked to evaluate the choice of concepts and check the content validity. Nineteen concepts were used in the formal study (see appendix C for the booklet for similarity rating).

The list of concepts that resulting from the pilot test is:

<table>
<thead>
<tr>
<th>force</th>
<th>velocity</th>
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<tbody>
<tr>
<td>acceleration</td>
<td>mass</td>
</tr>
<tr>
<td>weight</td>
<td>action</td>
</tr>
<tr>
<td>reaction</td>
<td>normal force</td>
</tr>
<tr>
<td>air pressure</td>
<td>friction</td>
</tr>
<tr>
<td>constant force</td>
<td>pull</td>
</tr>
</tbody>
</table>
The list focuses on 'force' and its related concepts. Among all concept pairs, some pairs were excluded because the relationship between them were very clear, such as force and increasing force. A total of eighty-seven concept pairs were used in the similarity ratings task.

Stage II: Similarity ratings and written description

During a week, the similarity ratings task was administered to the students in their own classroom. This occurred at different times on different days depending on the class schedules. Subjects were asked to indicate how closely the concepts are related for every possible pair of concepts by indicating the distance separating the concepts for each pair. Before the students began their rating job, the researcher explained the purpose and process of the study. Some examples were used to make the rating task clear. Students were encouraged to ask any related questions to clarify the purpose and the task. In addition to the rating task, students were asked to write briefly their understanding of the relationship between selected
pairs of concepts in order to check for guessing. The time needed for the rating task ranged from 30 to 50 minutes depending on the students and the classes responding. The distance data from the rating task were transformed to a proximity matrix according to a scale of 1 through 7. The data in the proximity matrix reflects the perceived relationship between concepts. A low number means short distance and strong relationship between concepts. Whereas a high number means far distance and weak relation (or unrelated). In the same week, three experienced teachers were asked to complete the same task. The median of the teachers' ratings were used to represent the content structure of the domain knowledge. The validity of students' similarity ratings task were checked by comparing teachers' ratings with those of high performance students. Cronbach α was calculated to estimate the similarity rating reliability. See appendix C for the booklet used in the classroom for the similarity ratings task.

Stage III: Force Concept Inventory testing

In the third stage, a multiple-choice misconception diagnostic instrument (Force Concept Inventory, FCI) was administered to the students in their own classrooms. The
responses were transformed to misconceptions according to the information provided by the FCI designers (see Instrumentation section).

Stage IV: Transformation of Pathfinder network and statistics calculations

After the data collection was completed, the Pathfinder algorithm was used to transform the data (proximity matrix) from the second stage to networks with the help of the computer program KNOT. Each concept is represented by a node in the network and relations between concepts are represented by links between nodes. Highly related concepts are directly connected and less related concepts are separated by indirect paths or may be entirely unconnected. For each concept pair, all paths between concepts (nodes) are compared and a direct link is connected between two nodes if this direct link is the minimum length path. By this process, Pathfinder reduces proximity data to the strongest relationships among concepts.

The students were divided into three groups according to their achievement scores. The data of high achievers (top 27% of all students) and low achievers (low 27% of all students) were selected for comparison. Then, similarity
and C index between each group and the content/teachers' structure, and between the two groups were compared for differences. In addition, the cognitive structures for those students with the same misconception were compared to test for similarity.

Stage V: Comparison of misconceptions and cognitive structure

In the last stage of the study, the data (the student's misconceptions) from misconception diagnostic test (FCI) were used to compared with the student's cognitive structure (Pathfinder network) to see if a relationship exists. The relationships between similarity ratings data and performance were also examined. In addition, the students' cognitive structures were analyzed to see if there were apparent hierarchical characteristics.

Hypotheses

In the research questions proposed by this study, the first (what are the cognitive structures of students) and fifth (does the Pathfinder network show hierarchical structure) questions were done by analysis of Pathfinder
network. In addition, three statistical hypotheses were tested in this study:

HYPOTHESIS #1-

There is no significant relationship between students' cognitive structures of Newtonian mechanics and their misconceptions.

HYPOTHESIS #2-

There is no significant difference in cognitive structure between low and high achievers.

HYPOTHESIS #3-

There is no significant difference in cognitive structures between high achievers and content/teachers.

Dependent/Independent Variables

The dependent variables in this study are (1) misconceptions: results on misconception diagnostic instrument (FCI), (2) cognitive structures: Pathfinder networks derived from similarity ratings, (3) Closeness index, and (4) Similarity index derived from Pathfinder networks. Independent variable is achievement level derived from classroom achievement tests.
Instrumentation

A Newtonian mechanics diagnostic instrument—Force Concept Inventory (FCI, see appendix B) was used in this study to test the students' force misconceptions.

The Force Concept Inventory (FCI) was developed by Hestenes, Wells and Swackhamer (1992). The items on the Inventory were specifically designed so students need to select between Newtonian concepts of force and commonsense alternatives that tend to be believed by many introductory physics students (Huffman & Heller, 1995). The Inventory data provide a clear, detailed picture of the problem of commonsense misconceptions in introductory physics.

FCI includes 29 multi-choice questions that are classified into six conceptual dimensions of mechanics—kinematics, first law, second law, third law, superposition principle and kinds of force. The six conceptual dimensions proposed by the developers are presented in Table 1. The developers had provided a classification of misconceptions probed by FCI (Table 2). The students' misconceptions can be diagnosed by their answers on the corresponding Inventory items. This instrument has been shown by the developers to be valuable at every level of introductory physics instruction from high school to university.
FCI was used in this study to diagnose Taiwanese high school students' misconceptions. However, three items—item 19, 20 and 21—are excluded because they are not directly related to the topic of this study. Therefore, the total number of items used in this study is 26. The reliability (KR20) was checked by using students' data, and the validity was examined by comparing FCI data with achievement scores. The Instrument was translated to Chinese for use in Taiwan.

The instrument for similarity ratings was developed by the researcher with the help of high school teachers in Taiwan. The Cronbach α of the similarity ratings task was checked; and the validity was checked by comparing the teachers' ratings and that of good performance students. The booklet for the similarity ratings task is in Appendix C.

The students' achievement scores were taken directly from students' classroom test written by their teachers on the topic of Newtonian mechanics after the instruction.
Table 1

Six Conceptual Dimensions in the Force Concept Inventory

<table>
<thead>
<tr>
<th>Conceptual dimension</th>
<th>Item number in FCI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Kinematics</td>
<td></td>
</tr>
<tr>
<td>velocity discriminated from position</td>
<td>20(^a)</td>
</tr>
<tr>
<td>acceleration discriminated from velocity</td>
<td>21(^a)</td>
</tr>
<tr>
<td>constant acceleration entails:</td>
<td></td>
</tr>
<tr>
<td>parabolic orbit</td>
<td>23[20(^b)]</td>
</tr>
<tr>
<td>changing speed</td>
<td>24[21]</td>
</tr>
<tr>
<td>2. First Law</td>
<td></td>
</tr>
<tr>
<td>with no force</td>
<td>4, 6, 10</td>
</tr>
<tr>
<td>velocity direction constant</td>
<td>26[23]</td>
</tr>
<tr>
<td>speed constant</td>
<td>8</td>
</tr>
<tr>
<td>with canceling forces</td>
<td>18</td>
</tr>
<tr>
<td>3. Second Law</td>
<td></td>
</tr>
<tr>
<td>impulsive force</td>
<td>6, 7</td>
</tr>
<tr>
<td>constant force implies constant acceleration</td>
<td>24[21]</td>
</tr>
<tr>
<td>25[22]</td>
<td></td>
</tr>
<tr>
<td>4. Third law</td>
<td></td>
</tr>
<tr>
<td>impulsive forces</td>
<td>2, 11</td>
</tr>
<tr>
<td>continuous forces</td>
<td>13, 14</td>
</tr>
<tr>
<td>5. Superposition principles</td>
<td></td>
</tr>
<tr>
<td>vector sum</td>
<td>19(^a)</td>
</tr>
<tr>
<td>canceling forces</td>
<td>9, 18</td>
</tr>
<tr>
<td>28[25]</td>
<td></td>
</tr>
<tr>
<td>6. Kinds of forces</td>
<td></td>
</tr>
<tr>
<td>6a. solid contact</td>
<td></td>
</tr>
<tr>
<td>passive</td>
<td>9, 12</td>
</tr>
<tr>
<td>impulsive</td>
<td>15</td>
</tr>
<tr>
<td>friction opposes motion</td>
<td>29[26]</td>
</tr>
<tr>
<td>6b. fluid contact</td>
<td></td>
</tr>
<tr>
<td>air resistance</td>
<td>22</td>
</tr>
<tr>
<td>buoyant (air pressure)</td>
<td>12</td>
</tr>
<tr>
<td>6c. gravitation</td>
<td></td>
</tr>
<tr>
<td>acceleration independent of weight</td>
<td>1, 3</td>
</tr>
<tr>
<td>parabolic trajectory</td>
<td>16</td>
</tr>
<tr>
<td>23[20]</td>
<td></td>
</tr>
</tbody>
</table>

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Table 1 (continued)

Note. From "Force Concept Inventory" by Hestenes et al., 1992, The Physics Teacher, 30, p. 142.
Some of the items contain more than one conceptual dimension in the question. a Items are not included in this study.
b The numbers in the brackets are the actual item numbers in this study, otherwise, FCI item numbers are the same as the item numbers in this study.
Table 2

Classification of Misconceptions and Corresponding FCI Items

<table>
<thead>
<tr>
<th>Misconceptions</th>
<th>Corresponding item and answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematics</td>
<td></td>
</tr>
<tr>
<td>position-velocity undiscriminated</td>
<td>20^aBCD</td>
</tr>
<tr>
<td>velocity-acceleration undiscriminated</td>
<td>20^aA</td>
</tr>
<tr>
<td>nonvectorial velocity composition</td>
<td>21^aBC</td>
</tr>
<tr>
<td>Impetus</td>
<td></td>
</tr>
<tr>
<td>impetus supplied by &quot;hit&quot;</td>
<td>9BCBCE[19]</td>
</tr>
<tr>
<td>loss/recovery of original impetus</td>
<td>24A[21]</td>
</tr>
<tr>
<td>impetus dissipation</td>
<td>5ABCDEFGHI</td>
</tr>
<tr>
<td>gradual/delayed impetus build-up</td>
<td>6D</td>
</tr>
<tr>
<td>circular impetus</td>
<td>4AD</td>
</tr>
<tr>
<td>Active force</td>
<td></td>
</tr>
<tr>
<td>only active agents exert forces</td>
<td>11B</td>
</tr>
<tr>
<td>motion implied active force</td>
<td>29A[26]</td>
</tr>
<tr>
<td>no motion implies no force</td>
<td>12E</td>
</tr>
<tr>
<td>velocity proportional to applied force</td>
<td>25A[22]</td>
</tr>
<tr>
<td>acceleration implies increasing force</td>
<td>17B</td>
</tr>
<tr>
<td>force causes acceleration to terminal velocity</td>
<td>17A</td>
</tr>
</tbody>
</table>

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<table>
<thead>
<tr>
<th>Misconceptions</th>
<th>Corresponding item and answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>active force wears out</td>
<td>25CE[22]</td>
</tr>
<tr>
<td>4. Action/Reaction pairs</td>
<td></td>
</tr>
<tr>
<td>greater mass implies greater force</td>
<td>2AD</td>
</tr>
<tr>
<td></td>
<td>11D</td>
</tr>
<tr>
<td></td>
<td>13B</td>
</tr>
<tr>
<td></td>
<td>14B</td>
</tr>
<tr>
<td>most active agent produces greater force</td>
<td>13C</td>
</tr>
<tr>
<td></td>
<td>11D</td>
</tr>
<tr>
<td></td>
<td>14C</td>
</tr>
<tr>
<td>5. Concatenation of influences</td>
<td></td>
</tr>
<tr>
<td>largest force determines motion</td>
<td>18AE</td>
</tr>
<tr>
<td></td>
<td>19°A</td>
</tr>
<tr>
<td>force compromise determines motion</td>
<td>4C</td>
</tr>
<tr>
<td></td>
<td>10D</td>
</tr>
<tr>
<td></td>
<td>16A</td>
</tr>
<tr>
<td></td>
<td>19°CD</td>
</tr>
<tr>
<td></td>
<td>23C[20]</td>
</tr>
<tr>
<td></td>
<td>24C[21]</td>
</tr>
<tr>
<td>last force to act determines motion</td>
<td>6A</td>
</tr>
<tr>
<td></td>
<td>7B</td>
</tr>
<tr>
<td></td>
<td>24B[21]</td>
</tr>
<tr>
<td></td>
<td>26C[23]</td>
</tr>
<tr>
<td>6. Other Influence on motion</td>
<td></td>
</tr>
<tr>
<td>centrifugal force</td>
<td>4CDE</td>
</tr>
<tr>
<td></td>
<td>10CDE</td>
</tr>
<tr>
<td>obstacles exert no force</td>
<td>2C</td>
</tr>
<tr>
<td></td>
<td>9AB</td>
</tr>
<tr>
<td></td>
<td>12A</td>
</tr>
<tr>
<td></td>
<td>13E</td>
</tr>
<tr>
<td></td>
<td>14E</td>
</tr>
<tr>
<td>resistance</td>
<td></td>
</tr>
<tr>
<td>mass makes things stop</td>
<td>29AB[26]</td>
</tr>
<tr>
<td></td>
<td>23AB[20]</td>
</tr>
<tr>
<td>motion when force overcomes resistance</td>
<td>28BD[25]</td>
</tr>
<tr>
<td>resistance opposes force/impetus</td>
<td>28E[25]</td>
</tr>
<tr>
<td>gravity</td>
<td></td>
</tr>
<tr>
<td>air pressure-assisted gravity</td>
<td>9A</td>
</tr>
<tr>
<td></td>
<td>12C</td>
</tr>
<tr>
<td></td>
<td>17E</td>
</tr>
<tr>
<td></td>
<td>18E</td>
</tr>
</tbody>
</table>
Table 2 (continued)

<table>
<thead>
<tr>
<th>Misconceptions</th>
<th>Corresponding item and answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>gravity intrinsic to mass</td>
<td>5E 9E 17D</td>
</tr>
<tr>
<td>heavier objects fall faster</td>
<td>1A 3BD</td>
</tr>
<tr>
<td>gravity increases as objects fall</td>
<td>5B 17B</td>
</tr>
<tr>
<td>gravity acts after impetus wears down</td>
<td>5B 16D 23E[20]</td>
</tr>
</tbody>
</table>

The characters after the item number are answers. a Items are not included in this study. b The numbers in the brackets are the actual item numbers in this study, otherwise, FCI item numbers are the same as the item numbers in this study.
Sample

The subjects were senior high school students (grade 11) in a rural area of middle Taiwan. The total sample numbered 156 from four different classes. The subjects had studied physics for two years (grade 8 and 9) in junior high school. After they had finished the study in junior high school, they passed an entrance examination to go to the senior high school. The students in this high school are among the middle ability level of high school students in Taiwan. The sample includes both male and female students. The students learned fundamental science which includes physics in the first year (grade 10) of senior high school and were enrolled in physics class in grade 11. The subjects had completed the study of Newtonian mechanics concepts and taken an achievement test before this study was conducted.

Of the 156 subjects, 129 completed the similarity ratings task, and 145 subjects took the test of Force Concept Inventory (FCI). The total effective sample was 117 after those subjects that didn’t complete both instruments or had missing data in the instruments were excluded.
The subjects were tested with intact groups in their own classrooms by their regular physics teachers and/or the researcher.
CHAPTER 4

RESULTS

Introduction

This chapter reports the results of data analysis related to the five principal research questions examined in this study. The data analyses are organized into eight sections. The reliability and validity of the two instruments are discussed in the first section. The second and third sections contain descriptive data about the Force Concept Inventory (FCI) and similarity ratings task. The data about the five research questions are discussed in section four through eight. In section four, Pathfinder networks data for different groups are summarized. The fifth section describes the correlation and regression analyses including FCI and similarity ratings. The relationships between misconceptions and cognitive structures are discussed in the sixth section. The seventh section reports the relationship between and among teachers,
high, and low performance students. Pathfinder network's hierarchical information is reported in the last section. In each section, there is also a brief explanation about the results in relation to the research question and/or hypothesis.

Results of Data Analyses

Reliability and Validity of Instruments

The internal consistency reliability of the Force Concept Inventory (FCI) was established using Kuder-Richardson formula (KR20). The data of FCI was first transformed according to the correctness of the answer, the correct answer was coded as 1 and others were 0, then KR20 was calculated and yielded the value of 0.661. Some FCI items (I2, I4, I12-I15) are found to have negative or almost zero correlation with other items. When these items are excluded, the KR20 increases to .744.

The validity of FCI was checked by comparing students' FCI total scores (sum of coded data) with their achievement scores related to mechanics concepts in the school. The Pearson product-moment correlation is 0.314 (p < .01). The correlation becomes 0.343 (p < .01) if the 6 FCI items discussed above are excluded.
Similarity ratings task’s reliability was examined by Cronbach $\alpha$, which has the value of 0.887. Besides the content validity checked by teachers in stage I of data collection, a criterion-related validity was used to examine the validity of the similarity ratings task. A Pearson product-moment correlation was calculated between the average similarity data of top achievers and teachers (content). A criterion-related validity coefficient of 0.733 ($p<.01$) was found for the similarity ratings task. The reliability and validity of the two instruments are summarized in Table 3.

Table 3
Reliability and Validity of FCI and Similarity Ratings Task

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Reliability</th>
<th>Validity</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCI</td>
<td>KR20 = 0.661</td>
<td>$r = 0.314^{**}$</td>
</tr>
<tr>
<td>Similarity Ratings</td>
<td>$\alpha = 0.887$</td>
<td>$r = 0.733^{**}$</td>
</tr>
</tbody>
</table>

Note. $^{**}p<.01$.  

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Force Concept Inventory Study

The data of FCI are summarized in Table 4; it shows the fraction of subjects' answers to each FCI item. For most items, except four items (5, 9, 13, 19) which will be discussed later, the correct response percentage is greater than that of any single incorrect response. Besides, there are two items (item 21 and 23) that students' responses are distributed across all answers; the response percentage for these items ranges from 12.8% to 35.9%.

Similarity Ratings Task

The median of teachers' data (content structure), average of total students, average of high achievement group (top 27% of sample), and average of low achievement group (low 27% of sample) are shown in Table 5. For each similarity pair, ratings ranged from 1 to 7. In all data, 29 pairs (33%) have means between 3.5 and 4.5. Those pairs for which teachers have congruent ratings (maximum ratings' difference equal to or less than 2) were marked by * in Table 5. The data shows that there are more congruent ratings (only 25% of them ranged from 3.5 to 4.5) among students for these congruent pairs.
For all similarity data, cluster analysis using SAS was done to examine FCI items, and resulted in no significant clusters based on students' ratings.

Table 4

Fraction of Answers to Force Concept Inventory (FCI)

<table>
<thead>
<tr>
<th>Item</th>
<th>Correct answer</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>blank^a</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C</td>
<td>0.034</td>
<td>0</td>
<td>.786</td>
<td>.162</td>
<td>.017</td>
<td>.009</td>
</tr>
<tr>
<td>2</td>
<td>E</td>
<td>0.085</td>
<td>0</td>
<td>.043</td>
<td>.009</td>
<td>.855</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>0.53</td>
<td>.222</td>
<td>.068</td>
<td>.145</td>
<td>.026</td>
<td>.009</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>0.026</td>
<td>.957</td>
<td>.017</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>0.068</td>
<td>.077</td>
<td>.496</td>
<td>.333</td>
<td>.017</td>
<td>.009</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>0.043</td>
<td>.573</td>
<td>.017</td>
<td>.162</td>
<td>.205</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>E</td>
<td>0.145</td>
<td>.162</td>
<td>.282</td>
<td>.051</td>
<td>.359</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>0.538</td>
<td>.128</td>
<td>.034</td>
<td>.265</td>
<td>.034</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>0.051</td>
<td>.162</td>
<td>.427</td>
<td>.325</td>
<td>.034</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>B</td>
<td>0.103</td>
<td>.769</td>
<td>.051</td>
<td>.060</td>
<td>0</td>
<td>.017</td>
</tr>
<tr>
<td>11</td>
<td>E</td>
<td>0.009</td>
<td>.017</td>
<td>.026</td>
<td>.043</td>
<td>.897</td>
<td>.009</td>
</tr>
<tr>
<td>12</td>
<td>B</td>
<td>0.009</td>
<td>.632</td>
<td>.282</td>
<td>.077</td>
<td>0</td>
<td>.009</td>
</tr>
<tr>
<td>13</td>
<td>A</td>
<td>0.359</td>
<td>.026</td>
<td>.479</td>
<td>.120</td>
<td>0</td>
<td>.017</td>
</tr>
<tr>
<td>14</td>
<td>A</td>
<td>0.709</td>
<td>.034</td>
<td>.051</td>
<td>.077</td>
<td>.111</td>
<td>.017</td>
</tr>
<tr>
<td>15</td>
<td>C</td>
<td>0.265</td>
<td>.154</td>
<td>.402</td>
<td>.034</td>
<td>.111</td>
<td>.034</td>
</tr>
<tr>
<td>16</td>
<td>B</td>
<td>0.009</td>
<td>.641</td>
<td>.333</td>
<td>.009</td>
<td>0</td>
<td>.009</td>
</tr>
<tr>
<td>17</td>
<td>C</td>
<td>0.017</td>
<td>.265</td>
<td>.667</td>
<td>.017</td>
<td>.034</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>B</td>
<td>0.274</td>
<td>.658</td>
<td>.017</td>
<td>.017</td>
<td>.017</td>
<td>.017</td>
</tr>
<tr>
<td>19</td>
<td>D</td>
<td>0.017</td>
<td>.017</td>
<td>.590</td>
<td>.368</td>
<td>0</td>
<td>.009</td>
</tr>
<tr>
<td>20</td>
<td>D</td>
<td>0.205</td>
<td>.034</td>
<td>.017</td>
<td>.735</td>
<td>0</td>
<td>.009</td>
</tr>
<tr>
<td>21</td>
<td>E</td>
<td>0.128</td>
<td>.137</td>
<td>.179</td>
<td>.179</td>
<td>.359</td>
<td>.017</td>
</tr>
<tr>
<td>22</td>
<td>B</td>
<td>0.077</td>
<td>.624</td>
<td>.034</td>
<td>.197</td>
<td>.051</td>
<td>.017</td>
</tr>
<tr>
<td>23</td>
<td>B</td>
<td>0.128</td>
<td>.325</td>
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Note. The total number of sample is 117.

^aFraction of students not responding to the question.
Table 5

Similarity Data of Different Groups (Teachers, Total Students, High Achievers, and Low Achievers)

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<td>6</td>
<td>4.6</td>
<td>3.11</td>
<td>4.4</td>
<td>2.64</td>
<td>5.0</td>
<td>3.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>75*</td>
<td>5</td>
<td>2.8</td>
<td>2.39</td>
<td>2.9</td>
<td>2.32</td>
<td>2.8</td>
<td>1.92</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5 (continued)

<table>
<thead>
<tr>
<th>Item</th>
<th>Teachers (Content)</th>
<th>Students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>median</td>
<td>mean</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>76</td>
<td>6</td>
<td>3.9</td>
</tr>
<tr>
<td>77*</td>
<td>6</td>
<td>4.8</td>
</tr>
<tr>
<td>78</td>
<td>5</td>
<td>3.8</td>
</tr>
<tr>
<td>79*</td>
<td>6</td>
<td>4.2</td>
</tr>
<tr>
<td>80*</td>
<td>6</td>
<td>5.1</td>
</tr>
<tr>
<td>81</td>
<td>3</td>
<td>3.1</td>
</tr>
<tr>
<td>82*</td>
<td>2</td>
<td>2.5</td>
</tr>
<tr>
<td>83*</td>
<td>6</td>
<td>3.0</td>
</tr>
<tr>
<td>84</td>
<td>5</td>
<td>3.4</td>
</tr>
<tr>
<td>85*</td>
<td>6</td>
<td>3.8</td>
</tr>
<tr>
<td>86</td>
<td>3</td>
<td>3.1</td>
</tr>
<tr>
<td>87</td>
<td>3</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Note. The data in this table are raw data of students' similarity ratings; low value means strong relationship and high value means weak relationship or not related.

*Pairs for which teachers have congruent ratings (maximum ratings range ≤ 2).
High achievers and low achievers' ratings on congruent concept pairs in Table 5 are shown in Figure 1. In Figure 1, X axis represents content/teachers' ratings median on congruent pairs, and Y axis represents high (H) and low (L) achievers' rating.

Figure 1. The ratings of high and low achievers on congruent concept pairs.
Research Question 1

Research question 1 asked what are high school students' cognitive structures of Newtonian mechanics? The Pathfinder networks (cognitive structure) of content/teachers, low achievers, and high achievers are shown in Figure 2-4. The Pathfinder network (PFnet) shows the important links among concepts and ignores the unimportant links. The content/teachers' PFnet has more links than students' PFnets, in addition, content/teachers' PFnet shows some star structures (such as normal force, friction, weight, reaction, and air pressure), and many triangle (such as constant force, free fall, and constant acceleration motion), or rectangle (such as projectile motion, increasing force, friction, and constant acceleration motion) relationships among concepts. On the contrary, low achievers' PFnet shows almost entirely linear structure and no triangles (or rectangle), which may mean students were not aware of some important relationships among concepts. Although the high achievers' PFnet is more similar to the content/teachers' PFnet than that of the low achievers, there are still no triangle (or rectangle) structures.

Both similarity index (Table 6) and C index (Table 7), whose calculations are described in Appendix A, show that
the high achievers' cognitive structure tends to be more similar to that of content/teachers than low achievers. In addition, cognitive structures of low achievers and high achievers are more similar to each other than to that of the content/teachers.
Figure 2. Content/Teachers Pathfinder network
constant velocity motion  free fall
constant force  projectile motion
constant acceleration motion

force

tension  pull  reaction  action  acceleration

air pressure  friction

increasing force  decreasing force
normal force  weight  mass

Figure 3. High achievers Pathfinder network
Figure 4. Low achievers Pathfinder network
Table 6
C Index Between PFnets of Content, High Achievers and Low Achievers

<table>
<thead>
<tr>
<th></th>
<th>Content</th>
<th>High Achievers</th>
<th>Low Achievers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Achievers</td>
<td>.396</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Low Achievers</td>
<td>.254</td>
<td>.462</td>
<td>1</td>
</tr>
</tbody>
</table>

Note. C index was calculated by calculator.
High C index means more similarity between two PFnets.

Table 7
Similarity Index Between PFnets of Content, High Achievers and Low Achievers

<table>
<thead>
<tr>
<th></th>
<th>Content</th>
<th>High Achievers</th>
<th>Low Achievers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High Achievers</td>
<td>.394</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Low Achievers</td>
<td>.243</td>
<td>.440</td>
<td>1</td>
</tr>
</tbody>
</table>

Note. Similarity index was calculated by KNOT program.
High similarity index means more similarity between two PFnets.
Research Question 2

Research question 2 asked whether a student’s cognitive structure can be used as a predictor of misconceptions. The null hypothesis is that there are no significant relationships between students’ cognitive structures assessed by similarity ratings task, and their misconceptions assessed by Force Concept Inventory (FCI).

For each item of FCI, the students’ responses were coded so that 1 represented correct response, and 0 means incorrect response. In addition, similarity data were transformed by subtracting the rating from eight so that high value means a strong relationship and low value means a weak relationship. Point-biserial correlations between each FCI item and similarity ratings pairs were then calculated; some correlations show significance to .05 or .01 level (Table 8).

For most correlated pairs, students who answered the FCI question correctly have a greater percentage of rating correctly on the similarity pair. For example, FCI item 1 has significant negative point-biserial correlation with similarity ratings task item 26 (r = -.269, p<.01) and 87 (r = -.333, p<.01). This means that students who answered FCI item 1 correctly (coded as 1) were inclined to rate
similarity rating items 26 and 87 low, which means weak or no relationship. According to the teachers, the two concepts in the similarity ratings task item 26 (projectile motion - increasing force) and item 87 (weight - free fall) are weakly related to each other.

In order to examine whether similarity ratings can be used to predict the correct answer on FCI, logistic regression of similarity pairs on FCI items was calculated (Table 9). In each row of Table 9, the list in the right hand column are the similarity ratings pairs, presented in order of their importance of prediction, that have significant predictive ability (p<.05) for the FCI item’s correct answer which is in the left hand column.

Moreover, in order to understand if there are any relationships between students’ incorrect responses (misconceptions) and their similarity ratings, logistic regression was used again. For each FCI item, every incorrect answer chosen by 10% or more of the students was coded as 1, and other answers were coded as 0, logistic regression was calculated to check whether the ratings on pairs can infer the choice of specific incorrect answers. The data are shown in Table 10. Results show that different
pairs have influence on the choices of incorrect answers (which represent various misconceptions).

Items with the same misconception (according to the classification of Hestenes et al. (1992)) were grouped together in Table 11 for comparison. The data in this table shows that different similarity pairs are related to different FCI items' answers even if these answers represent the same misconception as determined by Hestenes et al. (1992).
Table 8

FCI Item and Similarity Pairs (correct response) that have Significant Point-Biserial Correlation

<table>
<thead>
<tr>
<th>FCI item</th>
<th>Similarity items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>5-, 12-, 21-, 26-<em>, 28-, 53+, 63-, 87-</em></td>
</tr>
<tr>
<td>2</td>
<td>42-, 57-, 82-</td>
</tr>
<tr>
<td>3</td>
<td>11-, 12-<em>, 16+, 28-, 38-</em>, 41-, 59-, 77-, 78-, 83-</td>
</tr>
<tr>
<td>4</td>
<td>6+, 13+, 14-, 20-, 29+, 32+, 41+, 46-, 87-</td>
</tr>
<tr>
<td>5</td>
<td>4-, 5-<em>, 10+, 15-, 16+, 26-</em>, 28-<em>, 29-, 38-</em>, 42-, 3+, 56-*, 68-, 75-, 80-, 85-</td>
</tr>
<tr>
<td>6</td>
<td>24+, 48+, 83-</td>
</tr>
<tr>
<td>7</td>
<td>9+, 23+, 32-, 41-*, 66+, 80-</td>
</tr>
<tr>
<td>8</td>
<td>38-</td>
</tr>
<tr>
<td>9</td>
<td>11+, 12-, 16+, 26-, 31-, 36-*</td>
</tr>
<tr>
<td>10</td>
<td>3+, 5-, 16+, 35-, 68-, 69-, 78-</td>
</tr>
<tr>
<td>11</td>
<td>24+, 25-, 45-, 57-, 72-</td>
</tr>
<tr>
<td>12</td>
<td>8+, 14+, 15++, 22+, 29+, 34++, 35+, 38++, 50+, 64+, 79++</td>
</tr>
<tr>
<td>13</td>
<td>25-*, 35-, 66-, 69-</td>
</tr>
<tr>
<td>14</td>
<td>1-, 15-, 26-, 27-, 53-, 59-, 61-, 66-, 68-, 79-</td>
</tr>
<tr>
<td>15</td>
<td>1+, 11+, 32-, 49-, 76- *</td>
</tr>
<tr>
<td>16</td>
<td>5-, 8-, 17-<em>, 18-</em>, 19+, 28-, 32-, 38-, 50-<em>, 56-, 75-, 80-, 83-</em></td>
</tr>
<tr>
<td>17</td>
<td>3-, 12-, 16++, 22-, 42-</td>
</tr>
<tr>
<td>18</td>
<td>10+, 16+, 49-<em>, 56-</em>, 82+</td>
</tr>
<tr>
<td>19</td>
<td>5-, 6+, 10+, 15-, 16+, 17-, 21-<em>, 22-, 27-, 28-, 29-</em> 33+, 34-, 35-<em>, 38-</em>, 46-, 49-<em>, 50-</em>, 56-<em>, 65-, 68- 70-, 74-</em>, 80-, 81-*, 83-, 86-</td>
</tr>
</tbody>
</table>
Table 8 (continued)

<table>
<thead>
<tr>
<th>FCI item</th>
<th>Similarity items</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>9+, 15-, 24+</td>
</tr>
<tr>
<td>21</td>
<td>3+, 16++, 36--, 38--, 50--, 62--, 80-</td>
</tr>
<tr>
<td>22</td>
<td>6+, 9+, 12-, 16++, 33++, 36--, 38--, 43--, 44--, 52--, 60+</td>
</tr>
<tr>
<td>23</td>
<td>7+, 16+, 36--, 49--, 59--, 80--, 86+</td>
</tr>
<tr>
<td>24</td>
<td>53+</td>
</tr>
<tr>
<td>25</td>
<td>50--, 53+, 73+, 82++, 83-*</td>
</tr>
<tr>
<td>26</td>
<td>15--, 18--, 28--, 29--, 70--, 82-</td>
</tr>
</tbody>
</table>

Note. The similarity data have been transformed in this table so that high ratings value means strong relationship between two concepts. *p<.01, others p<.05. +/- signifies positive/negative correlation between similarity pair and FCI item.
### Table 9

Logistic Regression of Similarity Ratings Pairs on FCI Item

(Correct Response)

<table>
<thead>
<tr>
<th>FCI item</th>
<th>Answer</th>
<th>Similarity items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C</td>
<td>87, 26, 55</td>
</tr>
<tr>
<td>2</td>
<td>E</td>
<td>18, 57, 15, 82</td>
</tr>
<tr>
<td>3</td>
<td>A</td>
<td>75, 38, 64, 19, 18, 46, 12, 11, 78, 84, 50</td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>29, 20</td>
</tr>
<tr>
<td>5</td>
<td>D</td>
<td>4, 38, 53, 42, 56, 43, 3</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>83, 85, 48, 67</td>
</tr>
<tr>
<td>7</td>
<td>E</td>
<td>41, 66, 57, 23, 6, 9</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
<td>38, 8, 53</td>
</tr>
<tr>
<td>9</td>
<td>D</td>
<td>38, 13, 86, 11, 56, 30</td>
</tr>
<tr>
<td>10</td>
<td>B</td>
<td>3, 78, 5</td>
</tr>
<tr>
<td>11</td>
<td>E</td>
<td>25, 48, 24, 57, 62</td>
</tr>
<tr>
<td>12</td>
<td>B</td>
<td>38, 15, 6, 14, 79, 77, 22, 68</td>
</tr>
<tr>
<td>13</td>
<td>A</td>
<td>66, 78, 25, 70, 52, 20, 2, 83</td>
</tr>
<tr>
<td>14</td>
<td>A</td>
<td>26, 61, 48, 21, 63, 1, 33, 66, 57, 55, 53, 72, 42, 82</td>
</tr>
<tr>
<td>15</td>
<td>C</td>
<td>76, 11</td>
</tr>
<tr>
<td>16</td>
<td>B</td>
<td>83, 18, 24</td>
</tr>
<tr>
<td>17</td>
<td>C</td>
<td>7, 77, 8, 85, 16, 2, 70, 26, 3, 43, 10, 12, 1, 75, 31, 42</td>
</tr>
<tr>
<td>18</td>
<td>B</td>
<td>56, 49, 16, 64, 27</td>
</tr>
<tr>
<td>19</td>
<td>D</td>
<td>6, 35, 56, 10, 38, 71, 67</td>
</tr>
<tr>
<td>20</td>
<td>D</td>
<td>15, 79, 66, 52, 16</td>
</tr>
<tr>
<td>21</td>
<td>E</td>
<td>80, 36, 72, 61, 47, 48, 13, 60, 3, 86</td>
</tr>
<tr>
<td>22</td>
<td>B</td>
<td>40, 6, 33, 9</td>
</tr>
<tr>
<td>23</td>
<td>B</td>
<td>7, 49, 54, 86, 5, 59, 41</td>
</tr>
<tr>
<td>24</td>
<td>A</td>
<td>53</td>
</tr>
<tr>
<td>25</td>
<td>C</td>
<td>82, 83, 61</td>
</tr>
<tr>
<td>26</td>
<td>C</td>
<td>15</td>
</tr>
</tbody>
</table>

**Note.** Similarity ratings items are significant to .05 level.
Table 10

Logistic Regression of Similarity Ratings Pairs on FCI Item's Incorrect Responses with more than 10 Percent occurrence

<table>
<thead>
<tr>
<th>FCI</th>
<th>Answer</th>
<th>Similarity items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>D</td>
<td>87+, 70+, 21+, 12+, 23-</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>3-, 38+, 1+, 42+</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>58-, 80-, 22+, 36+, 39-</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>41-, 10+, 12+, 9-, 15+, 8-</td>
</tr>
<tr>
<td>4</td>
<td>C</td>
<td>3-, 38+, 1+, 42+</td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>58-, 80-, 22+, 36+, 39-</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>41-, 10+, 12+, 9-, 15+, 8-</td>
</tr>
<tr>
<td>6</td>
<td>C</td>
<td>32+, 37-</td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>36-, 28-</td>
</tr>
<tr>
<td>8</td>
<td>D</td>
<td>38+, 12+, 2-, 8-</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3-, 38+, 1+, 42+</td>
</tr>
<tr>
<td>9</td>
<td>B</td>
<td>72-, 15+, 12+, 62+, 75+, 51+, 25+, 28+</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>82+, 3-, 13+, 38+</td>
</tr>
<tr>
<td>10</td>
<td>A</td>
<td>14+</td>
</tr>
<tr>
<td>11</td>
<td>C</td>
<td>15-, 64-, 79-, 8-, 74+, 17+, 32-</td>
</tr>
<tr>
<td>12</td>
<td>B</td>
<td>22+, 85-</td>
</tr>
<tr>
<td>13</td>
<td>C</td>
<td>25+, 59-, 42+, 75-, 61-, 82-</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>81-, 19+, 70-</td>
</tr>
<tr>
<td>14</td>
<td>E</td>
<td>22-, 30+, 1, 71+, 21, 57-, 36-, 54-</td>
</tr>
<tr>
<td>15</td>
<td>A</td>
<td>76+, 73+, 48+</td>
</tr>
<tr>
<td>16</td>
<td>B</td>
<td>9+</td>
</tr>
<tr>
<td>17</td>
<td>C</td>
<td>83+, 70-, 75+, 50+, 16-</td>
</tr>
<tr>
<td>18</td>
<td>B</td>
<td>22+, 85-</td>
</tr>
<tr>
<td>19</td>
<td>A</td>
<td>49+, 10-</td>
</tr>
<tr>
<td>20</td>
<td>C</td>
<td>56+, 38+, 35+, 77-, 65+, 10-, 17+, 11-, 18+</td>
</tr>
<tr>
<td>21</td>
<td>A</td>
<td>9-</td>
</tr>
<tr>
<td>22</td>
<td>D</td>
<td>75+, 36+</td>
</tr>
<tr>
<td>23</td>
<td>C</td>
<td>16-, 43-, 64-, 35-, 77+, 40+, 82+, 17+</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>62-, 52-</td>
</tr>
<tr>
<td>24</td>
<td>B</td>
<td>18+, 39-</td>
</tr>
<tr>
<td>25</td>
<td>C</td>
<td>39-, 8-, 40-</td>
</tr>
</tbody>
</table>

Note. Similarity ratings items are significant to .05 level. Items are listed in the order of predictive contribution for FCI. +/- signifies positive/negative correlation between FCI item and similarity pair.
Table 11

Logistic Regression of Similarity Ratings Pairs on FCI Items
having the Same Misconception

<table>
<thead>
<tr>
<th>FCI Answer</th>
<th>Similarity items</th>
</tr>
</thead>
<tbody>
<tr>
<td>I1: Impetus supplied by 'hit'</td>
<td></td>
</tr>
<tr>
<td>9 C</td>
<td>82, 3, 13, 38</td>
</tr>
<tr>
<td>9 B</td>
<td>86, 32, 76, 8, 24, 13, 81, 63, 62, 30, 44, 51</td>
</tr>
<tr>
<td>19 C</td>
<td>56, 38, 35, 77, 65, 10, 17, 11, 18</td>
</tr>
<tr>
<td>I2: loss/recovery of original impetus</td>
<td></td>
</tr>
<tr>
<td>6 E</td>
<td>34, 33</td>
</tr>
<tr>
<td>23 D</td>
<td>62, 52</td>
</tr>
<tr>
<td>I3: impetus dissipation</td>
<td></td>
</tr>
<tr>
<td>5 C</td>
<td>3, 38, 1, 42</td>
</tr>
<tr>
<td>16 C</td>
<td>83, 70, 75, 50, 16</td>
</tr>
<tr>
<td>26 B</td>
<td>18, 39</td>
</tr>
<tr>
<td>I4: gradual/delayed impetus build-up</td>
<td></td>
</tr>
<tr>
<td>6 D</td>
<td>50</td>
</tr>
<tr>
<td>8 D</td>
<td>38, 12, 2, 8</td>
</tr>
<tr>
<td>8 B</td>
<td>72, 15, 12, 62, 75, 51, 25, 28</td>
</tr>
<tr>
<td>21 D</td>
<td>75, 36</td>
</tr>
<tr>
<td>I5: circular impetus</td>
<td></td>
</tr>
<tr>
<td>10 A</td>
<td>14</td>
</tr>
<tr>
<td>AF1: only active agents exert forces</td>
<td></td>
</tr>
<tr>
<td>13 D</td>
<td>81, 19, 70</td>
</tr>
<tr>
<td>15 A</td>
<td>76, 73, 48</td>
</tr>
<tr>
<td>15 B</td>
<td>9</td>
</tr>
<tr>
<td>AF2: motion implies active force</td>
<td></td>
</tr>
<tr>
<td>26 A</td>
<td>39, 8, 40</td>
</tr>
<tr>
<td>AF5: acceleration implies increasing force</td>
<td></td>
</tr>
<tr>
<td>17 B</td>
<td>22, 85</td>
</tr>
<tr>
<td>AF6: force causes acceleration to terminal velocity</td>
<td></td>
</tr>
<tr>
<td>22 D</td>
<td>33, 14</td>
</tr>
</tbody>
</table>
Table 11 (continued)

<table>
<thead>
<tr>
<th>FCI</th>
<th>Answer</th>
<th>Similarity items</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR2: most active agent produces greatest force</td>
<td>13 C</td>
<td>25, 59, 42, 75, 61, 82</td>
</tr>
<tr>
<td>CI1: largest force determines motion</td>
<td>18 A</td>
<td>49, 10</td>
</tr>
<tr>
<td>CI3: last force to act determines motion</td>
<td>7 B</td>
<td>36, 28</td>
</tr>
<tr>
<td></td>
<td>23 C</td>
<td>16, 43, 64, 35, 77, 40, 82, 17</td>
</tr>
<tr>
<td>OB: obstacles exert no force</td>
<td>14 E</td>
<td>22, 30, 1, 71, 21, 57, 36, 54</td>
</tr>
<tr>
<td>R2: motion when force overcomes resistance</td>
<td>25 D</td>
<td>50, 60</td>
</tr>
<tr>
<td>G1: air pressure-assisted gravity</td>
<td>12 C</td>
<td>15, 64, 79, 8, 74, 17, 32</td>
</tr>
<tr>
<td>G3: heavier objects fall faster</td>
<td>3 B</td>
<td>58, 80, 22, 36, 39</td>
</tr>
<tr>
<td></td>
<td>3 D</td>
<td>41, 10, 12, 9, 15, 8</td>
</tr>
<tr>
<td>K2: velocity-acceleration undiscriminated</td>
<td>20 A</td>
<td>9</td>
</tr>
<tr>
<td>K3: nonvectorial velocity composition</td>
<td>7 C</td>
<td>32, 37</td>
</tr>
<tr>
<td>Other⁵:</td>
<td>1 D</td>
<td>87, 70, 21, 12, 23</td>
</tr>
</tbody>
</table>

Note. Similarity ratings items are significant to .05 level. Items are listed in the order of predictive contribution for the FCI item. "Misconceptions were classified by Hestenes et al. (1992).

⁵not classified by Hestenes et al. (1992).
For the sake of understanding whether a similarity rating pair relates to a FCI item’s correct and incorrect responses, the data of Table 10 were rearranged to Table 12. In Table 12, for each row, a specific similarity ratings item and its concepts are placed on the left hand side. This pair has predictive ability to the FCI item’s correct response (see Table 9) and the incorrect response with the highest incidence of selection (see Table 10) on the right hand side. For example, in the first row, similarity pair 87 (free fall - weight) shows predictive power for the correct response (C) for FCI item 1 and for incorrect response (D) for that item. The - or + after the FCI item indicates negative or positive correlation between the similarity pair and the FCI item, and the number in the bracket represents the importance of the similarity pair’s predictive ability to that FCI item’s correct (or incorrect) response (according to the list order of Table 9 & 10). The data showed that 17 similarity pairs, out of the total 87 pairs, influenced both the choice of correct and incorrect responses on the same FCI item. The results show that some of the similarity pairs have predictive ability with respect to FCI question responses.
Table 12

FCI Items for which Correct and Incorrect Responses are Predicted by the Same Similarity Pair

<table>
<thead>
<tr>
<th>Similarity item concept pair</th>
<th>FCI item</th>
<th>correct</th>
<th>wrong</th>
</tr>
</thead>
<tbody>
<tr>
<td>(87) free fall weight</td>
<td>1\textsuperscript{a}-[1\textsuperscript{b}]</td>
<td>1+[1]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>8+[1]</td>
<td>8+[1]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3+[2]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>12-[1]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(76) air pressure friction</td>
<td>15-[1]</td>
<td>15+[1]</td>
<td></td>
</tr>
<tr>
<td>(83) constant velocity motion constant force</td>
<td>16-[1]</td>
<td>16+[1]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6-[1]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>13+[8]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>25-[3]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(36) constant velocity motion projectile motion</td>
<td>21-[2]</td>
<td>21+[2]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3+[4]</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14-[7]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(13) friction constant force</td>
<td>9-[2]</td>
<td>9+[3]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>21+[7]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(35) velocity tension</td>
<td>19-[2]</td>
<td>19+[3]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>23-[4]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(25) friction tension</td>
<td>13-[3]</td>
<td>13+[1]</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11-[1]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 12 (continued)

<table>
<thead>
<tr>
<th>Similarity</th>
<th>FCI item</th>
</tr>
</thead>
<tbody>
<tr>
<td>item concept pair</td>
<td>correct</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>(56) weight force</td>
<td>19-[3]</td>
</tr>
<tr>
<td></td>
<td>5-[5]</td>
</tr>
<tr>
<td></td>
<td>9-[5]</td>
</tr>
<tr>
<td></td>
<td>18-[1]</td>
</tr>
<tr>
<td>(33) constant acceleration motion free fall</td>
<td>22+[3]</td>
</tr>
<tr>
<td></td>
<td>14-[7]</td>
</tr>
<tr>
<td>(85) reaction weight</td>
<td>17+[4]</td>
</tr>
<tr>
<td></td>
<td>6+[2]</td>
</tr>
<tr>
<td>(15) action tension</td>
<td>12+[5]</td>
</tr>
<tr>
<td></td>
<td>2-[3]</td>
</tr>
<tr>
<td></td>
<td>20-[1]</td>
</tr>
<tr>
<td></td>
<td>26-[1]</td>
</tr>
<tr>
<td>(79) constant acceleration motion decreasing force</td>
<td>12+[5]</td>
</tr>
<tr>
<td></td>
<td>20+[2]</td>
</tr>
<tr>
<td>(1) velocity acceleration</td>
<td>14-[6]</td>
</tr>
<tr>
<td>(3) free fall force</td>
<td>5+[7]</td>
</tr>
<tr>
<td></td>
<td>10+[1]</td>
</tr>
<tr>
<td></td>
<td>17-[9]</td>
</tr>
<tr>
<td></td>
<td>21+[9]</td>
</tr>
<tr>
<td>(57) mass acceleration</td>
<td>14+[9]</td>
</tr>
<tr>
<td></td>
<td>2-[2]</td>
</tr>
<tr>
<td></td>
<td>7-[3]</td>
</tr>
<tr>
<td></td>
<td>11-[4]</td>
</tr>
</tbody>
</table>

96
Table 12 (continued)

Note. Similarity pairs are listed according to the importance of their predictive ability to FCI correct answer. +/- signifies positive/negative point-biserial correlation between FCI item and similarity pair.
a FCI item no. b The degree of importance of the similarity pair to that FCI item (1 signifies the most important).

Research Question 3

Research question 3 asked whether students that share the same misconception have similar cognitive structure. The null hypothesis is that students that share the same misconception do not share the same cognitive structure.

For each FCI item, those students who gave the most high percentage incorrect response (a specific misconception) were chosen to be a group, and the students who gave correct response to that FCI item were chosen as another group. Two groups' variances of all similarity rating pairs were compared by pair-comparison T-test to examine which group had smaller similarity ratings variance, which means that the students in the group had more consistent ratings on the similarity ratings task. Two T-tests were carried out to test the difference, the first one
compared two groups' whole similarity pairs data (Table 13), and the second T-test compared two groups' ratings data on the 17 pairs discussed in previous section (Table 14). The results reveal that, for most FCI items (e.g., 15 out of 22 items in Table 13 and 17 out of 22 items in Table 14), students with a specific misconception tend to show less variance on their similarity ratings, which means they had more consistent similarity ratings (and also, more consistent cognitive structure). However, although 10 of the 15 differences in Table 13 are statistical significant (p<.05 or p<.01), only 3 differences are statistically significant in Table 14.
Table 13

Pair-comparison (87 pairs) T-test for the Difference of the
Variance of Similarity Ratings of Two Groups (Response to
FCI Item Correct and Incorrect)

<table>
<thead>
<tr>
<th>FCI item</th>
<th>N&lt;sub&gt;c&lt;/sub&gt;</th>
<th>N&lt;sub&gt;W&lt;/sub&gt;</th>
<th>mean difference variance</th>
<th>Std</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>63</td>
<td>31</td>
<td>0.32</td>
<td>0.72</td>
<td>4.18</td>
<td>0.0001**</td>
</tr>
<tr>
<td>13</td>
<td>42</td>
<td>56</td>
<td>0.69</td>
<td>0.68</td>
<td>9.46</td>
<td>0.0001**</td>
</tr>
<tr>
<td>22</td>
<td>73</td>
<td>23</td>
<td>0.56</td>
<td>0.93</td>
<td>5.60</td>
<td>0.0001**</td>
</tr>
<tr>
<td>26</td>
<td>65</td>
<td>22</td>
<td>0.53</td>
<td>0.73</td>
<td>6.80</td>
<td>0.0001**</td>
</tr>
<tr>
<td>3</td>
<td>62</td>
<td>26</td>
<td>0.37</td>
<td>0.88</td>
<td>3.97</td>
<td>0.0002**</td>
</tr>
<tr>
<td>20</td>
<td>86</td>
<td>24</td>
<td>0.27</td>
<td>0.70</td>
<td>3.59</td>
<td>0.0006**</td>
</tr>
<tr>
<td>21</td>
<td>42</td>
<td>21</td>
<td>0.31</td>
<td>0.88</td>
<td>3.25</td>
<td>0.0016**</td>
</tr>
<tr>
<td>7</td>
<td>42</td>
<td>33</td>
<td>0.21</td>
<td>0.74</td>
<td>2.62</td>
<td>0.0103*</td>
</tr>
<tr>
<td>1</td>
<td>92</td>
<td>19</td>
<td>0.24</td>
<td>0.95</td>
<td>2.38</td>
<td>0.0193*</td>
</tr>
<tr>
<td>5</td>
<td>39</td>
<td>58</td>
<td>0.17</td>
<td>0.76</td>
<td>2.09</td>
<td>0.0395*</td>
</tr>
<tr>
<td>17</td>
<td>78</td>
<td>31</td>
<td>0.14</td>
<td>0.68</td>
<td>1.92</td>
<td>0.0581</td>
</tr>
<tr>
<td>18</td>
<td>77</td>
<td>32</td>
<td>0.12</td>
<td>0.73</td>
<td>1.54</td>
<td>0.1272</td>
</tr>
<tr>
<td>10</td>
<td>90</td>
<td>12</td>
<td>0.16</td>
<td>0.99</td>
<td>1.47</td>
<td>0.1446</td>
</tr>
<tr>
<td>23</td>
<td>38</td>
<td>30</td>
<td>0.12</td>
<td>0.95</td>
<td>1.14</td>
<td>0.2558</td>
</tr>
<tr>
<td>25</td>
<td>72</td>
<td>23</td>
<td>0.07</td>
<td>0.94</td>
<td>0.66</td>
<td>0.5089</td>
</tr>
<tr>
<td>9</td>
<td>38</td>
<td>50</td>
<td>-0.11</td>
<td>0.79</td>
<td>-1.39</td>
<td>0.1683</td>
</tr>
<tr>
<td>14</td>
<td>83</td>
<td>13</td>
<td>-0.24</td>
<td>1.22</td>
<td>-1.79</td>
<td>0.0767</td>
</tr>
<tr>
<td>12</td>
<td>74</td>
<td>33</td>
<td>-0.14</td>
<td>0.67</td>
<td>-1.93</td>
<td>0.0569</td>
</tr>
<tr>
<td>6</td>
<td>67</td>
<td>24</td>
<td>-0.18</td>
<td>0.80</td>
<td>-2.12</td>
<td>0.0366*</td>
</tr>
<tr>
<td>16</td>
<td>75</td>
<td>39</td>
<td>-0.18</td>
<td>0.80</td>
<td>-2.12</td>
<td>0.0366*</td>
</tr>
<tr>
<td>15</td>
<td>47</td>
<td>31</td>
<td>-0.21</td>
<td>0.80</td>
<td>-2.51</td>
<td>0.0139*</td>
</tr>
<tr>
<td>19</td>
<td>43</td>
<td>69</td>
<td>-0.27</td>
<td>0.79</td>
<td>-3.20</td>
<td>0.0020**</td>
</tr>
</tbody>
</table>

Note. Difference of the variance = rating variance of correct group - rating variance of incorrect group (for each pair of all 87 pairs). Mean difference of the variance = mean of all difference of the variance. *p<.05. **p<.01.
Table 14

Pair-comparison (17 pairs) T-test for the Difference of the Variance of Similarity Ratings of Two Groups (Response to FCI Item Correct and Incorrect)

<table>
<thead>
<tr>
<th>FCI item</th>
<th>N_c</th>
<th>N_w</th>
<th>mean difference variance</th>
<th>Std</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>13</td>
<td>42</td>
<td>56</td>
<td>0.67</td>
<td>0.68</td>
<td>4.07</td>
<td>0.0009**</td>
</tr>
<tr>
<td>26</td>
<td>65</td>
<td>22</td>
<td>0.52</td>
<td>0.87</td>
<td>2.46</td>
<td>0.0256*</td>
</tr>
<tr>
<td>22</td>
<td>73</td>
<td>23</td>
<td>0.63</td>
<td>1.21</td>
<td>2.14</td>
<td>0.0478*</td>
</tr>
<tr>
<td>8</td>
<td>63</td>
<td>31</td>
<td>0.47</td>
<td>0.94</td>
<td>2.09</td>
<td>0.0532</td>
</tr>
<tr>
<td>1</td>
<td>92</td>
<td>19</td>
<td>0.57</td>
<td>1.16</td>
<td>2.02</td>
<td>0.0599</td>
</tr>
<tr>
<td>20</td>
<td>86</td>
<td>24</td>
<td>0.32</td>
<td>0.69</td>
<td>1.93</td>
<td>0.0714</td>
</tr>
<tr>
<td>18</td>
<td>77</td>
<td>32</td>
<td>0.31</td>
<td>0.68</td>
<td>1.90</td>
<td>0.0760</td>
</tr>
<tr>
<td>3</td>
<td>62</td>
<td>26</td>
<td>0.44</td>
<td>0.97</td>
<td>1.97</td>
<td>0.0798</td>
</tr>
<tr>
<td>23</td>
<td>38</td>
<td>30</td>
<td>0.35</td>
<td>0.92</td>
<td>1.56</td>
<td>0.1387</td>
</tr>
<tr>
<td>16</td>
<td>75</td>
<td>39</td>
<td>0.23</td>
<td>0.72</td>
<td>1.35</td>
<td>0.1955</td>
</tr>
<tr>
<td>25</td>
<td>72</td>
<td>23</td>
<td>0.32</td>
<td>1.08</td>
<td>1.23</td>
<td>0.2361</td>
</tr>
<tr>
<td>5</td>
<td>39</td>
<td>58</td>
<td>0.22</td>
<td>0.84</td>
<td>1.08</td>
<td>0.2972</td>
</tr>
<tr>
<td>7</td>
<td>42</td>
<td>33</td>
<td>0.23</td>
<td>1.00</td>
<td>0.93</td>
<td>0.3647</td>
</tr>
<tr>
<td>10</td>
<td>90</td>
<td>12</td>
<td>0.21</td>
<td>1.02</td>
<td>0.84</td>
<td>0.4126</td>
</tr>
<tr>
<td>17</td>
<td>78</td>
<td>31</td>
<td>0.10</td>
<td>0.58</td>
<td>0.75</td>
<td>0.4644</td>
</tr>
<tr>
<td>9</td>
<td>38</td>
<td>50</td>
<td>0.07</td>
<td>0.90</td>
<td>0.30</td>
<td>0.7682</td>
</tr>
<tr>
<td>21</td>
<td>42</td>
<td>21</td>
<td>0.02</td>
<td>0.92</td>
<td>0.07</td>
<td>0.9414</td>
</tr>
<tr>
<td>6</td>
<td>67</td>
<td>24</td>
<td>-0.08</td>
<td>0.70</td>
<td>-0.49</td>
<td>0.6336</td>
</tr>
<tr>
<td>14</td>
<td>83</td>
<td>13</td>
<td>-0.25</td>
<td>1.40</td>
<td>-0.74</td>
<td>0.4676</td>
</tr>
<tr>
<td>15</td>
<td>47</td>
<td>31</td>
<td>-0.14</td>
<td>0.51</td>
<td>-1.14</td>
<td>0.2701</td>
</tr>
<tr>
<td>19</td>
<td>43</td>
<td>69</td>
<td>-0.20</td>
<td>0.68</td>
<td>-1.22</td>
<td>0.2412</td>
</tr>
<tr>
<td>12</td>
<td>74</td>
<td>33</td>
<td>-0.40</td>
<td>0.78</td>
<td>-2.14</td>
<td>0.0485*</td>
</tr>
</tbody>
</table>

Note. Difference of the variance = rating variance of correct group - rating variance of incorrect group (for each pair of all 17 pairs). Mean difference of the variance = mean of all difference of the variance. *p<.05. **p<.01.
Among all FCI items, there are some items where the percentage of students who gave specific incorrect responses is greater than the percentage of correct responses. These items are 5, 9, 13 and 19 (see Table 4). In item 13, many students asserted that, while a car is pushing a truck forward, the car needs to exert larger force on the truck than the truck exerts on the car. This idea opposes the concept of Newton's third law, which says that the car and the truck both exert the same force on each other (action and reaction). In item 5, 9 and 19, no matter what the moving object is or how it moves, many students asserted that a force (impetus) is needed to keep the object moving even though there is no acting agent against the object during the motion. Although these four question are different, the major misconception concerning the choice of these wrong answers is that many students believed that a force must exist in the direction of motion to keep an object moving, whether the motion has acceleration or not.

Among all subjects, 10 students gave incorrect responses to all the above four questions, and 7 students responded to all of them correctly. In order to compare the cognitive structures of students who responded to all four questions correctly and students who responded to all four
questions incorrectly, 7 students were randomly selected from the 10 students who responded to all four questions incorrectly so as to compare with those 7 students who responded correctly. Differences between these two groups were examined by comparing within group similarity indexes using the T-test, the result (Table 15) shows that the group without this misconception tends to have a larger within group similarity index than the group with misconception. However, the difference was not significant at .05 level. In general, the results of this study failed to reject the null hypothesis, that is students that share the same misconception don’t show more similar cognitive structure with each other than students without misconception.
Table 15
T-test on Difference of Two Groups' Similarity Index

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>mean</th>
<th>SD</th>
<th>df</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>21</td>
<td>.299</td>
<td>.051</td>
<td>40</td>
<td>.174</td>
</tr>
<tr>
<td>1</td>
<td>21</td>
<td>.303</td>
<td>.087</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note.  °0 = group with all 4 questions incorrect, 1 = group with all 4 questions correct.  °p>.05.

Research Question 4

Research question 4 asked whether high performance students have cognitive structure similar to that of their teachers. The null hypothesis is that there is no significant difference between (1) the similarity of high achievers and content/teachers, and (2) the similarity of low achievers and content/teachers. Closeness index and similarity index between median of content/teachers' PFnets, average of high achievers' PFnets, and average of low achievers' PFnets were calculated (shown in Table 6 and 7).

Both indexes showed that high achievers' PFnet is more similar to content/teachers'. In order to check whether the
difference is significant, the PFnet of each student in the two groups was compared with content/teachers' PFnet to calculate similarity indexes. T-test statistics were examined (Table 16) and the data showed that the difference is significant to .05 level. The null hypothesis was rejected. In addition, correlation between subjects' similarity indexes and their achievement scores were calculated and had the value of .33 (p < .01), the result showed that cognitive structure (through similarity index) can be used as an evaluation tool for students' learning.

Table 16
T-test on Similarity Index of PFnet between Content/Teachers, High Achievers, and Low Achievers

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>mean</th>
<th>SD</th>
<th>df</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cont. &amp; High</td>
<td>32</td>
<td>.300</td>
<td>.069</td>
<td>62</td>
<td>2.0716*</td>
</tr>
<tr>
<td>Cont. &amp; Low</td>
<td>32</td>
<td>.265</td>
<td>.065</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. *p<.05.
Research Question 5

Research question 5 asked whether Pathfinder network can provide hierarchical information that is implied implicitly in the raw data. Based on the content/teachers' and students' Pathfinder networks (Figure 2-4), no hierarchical relationships are apparent. For example, 'action', 'reaction', 'tension' and 'weight' are different types of forces and should be subsets of 'force', a more general term. Therefore, in the Pathfinder network, they should all connect to 'force' to form a star structure. However, although PFnets show some connections among those concepts, the links are not completed. For example, these concepts in content/teachers' PFnet (Figure 2) show many interactions but only part of the star shape, while they are in linear formation in the low achievers' PFnet. The Pathfinder networks examined in this study don't provide complete hierarchical information. The reason may come from the existence of several relationships between similarity concept pairs depending on different conditions, and the raters gave different ratings based on different conditions.
Summary

In this study, 117 Taiwanese high school students, a convenient sample, were used to collect misconceptions and similarity ratings data on Newtonian mechanics. In addition, three teachers were asked to rate similarity concept pairs to represent content structure. The difference of similarity ratings between different performance subjects and teachers were examined, and the relationship between subjects' misconceptions and similarity ratings were studied. The similarity rating data show that the cognitive structures are different among three groups: content/teachers, high achievers, and low achievers. Based on the results of T-tests on the C index and the similarity index, the cognitive structures of high achievers are more similar to that of content/teachers. The results of point-biserial correlation and logistic regression show that there are relationships between subjects' similarity pair ratings and misconceptions. Evidence suggests that some of the pairs' ratings can predict students' responses to FCI items. The similarity rating (and also cognitive structure) difference between students with and without specific
misconceptions is not significant. In addition, students' Pathfinder networks do not show complete hierarchical structures in the networks.
CHAPTER 5

DISCUSSION AND CONCLUSION

Introduction

This final chapter is devoted to a summary and discussion of the results. First, an overview of the purpose and methodology is presented, followed by discussion of findings and conclusion based on the findings. Finally, recommendations for practice and an agenda for further investigation are discussed.

Overview of the study

Learning is a process of restructuring knowledge structure by adding new knowledge or modifying old knowledge (Gonzalvo et al., 1994). Several studies have shown that student knowledge structures become more similar to that of the instructor after the instruction (Goldsmith et al.,
Therefore, understanding the cognitive structure of a domain knowledge should help teachers evaluate what the student has learned. Shavelson (1972) pointed out that the knowledge of how students structure a body of knowledge can help the development of curriculum and the formation of instruction in order that the instruction can be more effective.

Students come to school with misconceptions derived from children's own experience of the world. Educators believe that misconception may make students' learning difficult (Clement, 1982). Studies show that students retain their misconceptions even after the instruction. It is important to understand the ideas and beliefs that young people bring to their formal study of science, so these ideas can be successfully modified by instruction.

Physics is usually considered by most students as a difficult subject. According to Clement (1982), there are many reasons for the difficulty of learning physics, one of them is the student's preconceived ideas about how the world works. Because of the experiences of daily life, students bring their individual preconceptions of mechanics to the classroom. Some of them are misconceptions that adversely influence their learning of Newtonian mechanics. Thus
Newtonian mechanics is a difficult topic in middle- and high-school physics. When teaching mechanics, teachers need to know what misconceptions influence the reasoning of students in problem solving so remediation can be designed for their specific difficulties and therefore be more effective (Bright, 1984).

Learning is a process of building and modification of the learner's cognitive structure. Before classroom learning, students have their own cognitive structures about a domain knowledge; some of them are incorrect relationships between concepts. When learning the knowledge in the classroom, students may modify their cognitive structure to make it similar to the structure of the instructor. However, some students may ignore the instruction because new materials are different from their original structure, or just incorporate part of the knowledge into their own structure- to enhance their misconception by giving justification from the class learning. Their cognitive structures must have different inter-relationships from the correct structure.

In traditional classrooms, teachers use paper/pencil tests to evaluate all students' understanding of the concepts. However, using the same kind of tests for
everyone may not be appropriate because each student has a different knowledge state. Moreira and Santos (1981) pointed out that achievement tests in physics are usually concerned with the student's problem-solving ability. However, these tests don't provide any information about the student's cognitive structure, which might be responsible for his/her ability to solve problems. If the student's cognitive structure in memory can be represented externally, which would permit the visualization of the relationships among concepts, then the instructor can better assess the student's understanding.

Pathfinder algorithm is a graph-based technique that derives network structure from proximity data. By using a proximity matrix, the Pathfinder algorithm creates a network in which concepts are represented as nodes and relations between concepts represented as links between the nodes. Pathfinder algorithm has been used by many researchers in the study of students' cognitive structures and has proven that it can successfully represent cognitive structure. However, almost all studies using Pathfinder have focused on psychology or social science (Durso & Coggins, 1990), except one study related to physical science—chemical equilibrium (Wilson, 1994). Koubek and Mountjoy (1991) pointed out that
different ways of measuring cognitive structure may be appropriate for different domain knowledge. To determine whether the Pathfinder algorithm can be effectively used in physics is one of the purposes of this study.

The question of how students organize their domain knowledge structures differently and their relations with misconceptions and performance is the focus of the study. A group of high school students from middle Taiwan were used to collect data; students' cognitive structures related to Newtonian mechanics were extracted by the similarity ratings and Pathfinder algorithm and used to determine whether the student's cognitive structure can be used as a predictor of misconceptions; also, the relationship between cognitive structure and achievement performance was examined.

Specifically, this study seeks to answer the following questions:
1. What are the high school students' cognitive structures of Newtonian mechanics?
2. Can cognitive structure assessed by similarity ratings and Pathfinder algorithm be a valid predictor of misconception?
3. Do students that share the same misconception have similar cognitive structure?
4. Do high performance students have structures similar to that of their teachers?
5. Can the Pathfinder network provide hierarchical information that is implied implicitly in the raw data?

Discussion of Findings

The results of FCI test are shown in Table 4; the data show that many students still have misconceptions although they had studied physics more than three years. In some questions, the proportion of students who had misconceptions was even greater than those who had correct concepts. This result demonstrates, as many misconception studies had done before, that students retain their misconceptions even after instruction.

The data of the similarity ratings task are summarized in Table 5. For every similarity pair, students' ratings range from 1 to 7, even on those pairs that teachers rated congruously (the range of three teachers' ratings are smaller than 2). It may mean that students don't have a clear idea about the relationships; they didn't learn the concepts well. There are many pairs rated diversely even by teachers. According to the small group discussion after the
pilot study and review of the students' brief written answers to some pairs, many concept pairs have several different relationships due to conditions other than misconceptions. For example, when considering weight and velocity, some may say velocity is caused by force, it's not related to weight; but some may think another way- in the condition of gravitational force, weight (mass) will influence the acceleration and also velocity. Another example, force and constant velocity motion, some may think they are not related because when an object moves with constant velocity, there is no net force acting on it; however, some may say that a force is needed to initiate a motion or a force is needed to keep an object moving constantly if friction exists. Apparently, the perceived relationship between two physics concepts depends on the environment or condition, and may be more complicated than psychology or other social sciences. Therefore, the selection of concept pairs must be considered carefully in future study in order to prevent this kind of relationship vagueness when a similarity ratings task is used in physics. In addition, only 17 similarity pairs are found to have predictive ability on both correct and incorrect responses to FCI items. The selection of appropriate concept pairs
should be done through consideration of the results of this study, specific misconceptions of interest, and findings from other studies.

Research question 1 asked what are high school students' cognitive structures of Newtonian mechanics? Based on the results of this study, similarity ratings show good reliability (Cronbach $\alpha = 0.887$) and validity (criterion-related validity = 0.733) on rating students' knowledge. The cognitive structures are visualized by means of the Pathfinder algorithm and show some similarity between content/teachers' structure and students' structures. The structures of high performance students and low performance students are shown in Figures 3 and 4 (Chapter 4).

Research question 2 asked whether a cognitive structure assessed by similarity ratings and Pathfinder algorithm can be used to predict misconceptions? The results of point-biserial correlations between similarity ratings pairs and FCI items (Table 8) and logistic regression of similarity pairs on FCI items (Table 9 & 10) show that some relationships exist between similarity ratings and responses to FCI (correct answers or misconceptions).

For example, as shown in Table 9, similarity pairs 87, 26 and 55 contribute to the selection of answer C (correct
response) to FCI item 1. The three similarity pairs are weight − free fall (87), projectile motion − increasing force (26), and pull-reaction (55). FCI item 1 asks whether two balls (a heavier one and a lighter one) take the same time period to drop to the ground in free fall motion. The point-biserial correlation between FCI item 1 (correct response) and similarity pair 87 is negative (Table 8, $r = -0.33, p<.01$), which means those who rate pair 87 low (weak related or unrelated), would respond to FCI item 1 correctly. On the other hand, similarity pair 87 also contributes to the selection of FCI item 1's incorrect answer (Table 10) and their correlation is positive ($r = +0.29, p<.01$), which means students who rate pair 87 high are inclined to respond FCI item incorrectly. The prediction is quite apparent, if students understand free fall time is not related to weight; they would know both objects (the heavier one and the lighter one) will drop to the ground in the same time interval.

The correlation between FCI item 1 (correct response) and similarity pair 26 (projectile motion − increasing force) is also negative ($r = -0.27, p<.01$); it means students who rate this pair low (correctly) would also respond to FCI item 1 correctly. If students understand
that the moving object suffers only a constant force (gravity) in projectile motion (free fall is one of them),
they surely know the correct answer. However, some students think the force acting on the moving object would be
different according to the object's weight, therefore they may think that the heavier object would drop faster than the
lighter one. Correlation between Similarity pair 55 and FCI item 1 (correct response) is positive ($r = 0.16, p<.05$),
it's also a correct relationship. However, how the understanding of this concept pair's relationship can influence the response to the FCI item 1 is not clear. The relationship between this concept pair and FCI item response is not readily apparent.

Part of the data in Table 9 and 10 are transformed to Table 12, which shows how a similarity item influences both the correct and incorrect responses to the same FCI item. The first pair (87) had been discussed above, students who rate similarity pair 87 high (incorrect relationship) would give incorrect response to FCI item 1, which means a type of misconception. Students who rate pair 76 (air pressure - friction) high would respond FCI item 15 incorrectly. FCI item 15 asks why a dropping rubber ball will bounce off the floor; the correct answer is that the floor exerts a force
on the ball to stop its fall and drives it upward. Many students who think air pressure has some relationship with friction chose the wrong reason that the energy of the ball is conserved. The direct relation between this pair and FCI item is not readily apparent. One possible explanation is that if students have the idea that air pressure is a kind of friction which can cause the dissipation of energy, they would rate this pair high, and when considering the question of rubber ball's motion in the air, they may retrieve and combine all these concepts together and find an answer from this cluster of concepts. "Energy" appears in the concept cluster and the FCI question's answer list, it may contribute to the students' selection of the "energy" answer.

The findings reveal that some similarity pairs' ratings indeed can predict students' answers on FCI questions (see Table 12). Novak and Gowin (1984) proposed that misconceptions are usually "signaled either by a linkage between two concepts that leads to a clearly false proposition or by a linkage that misses the key idea relating two or more concepts" (p. 20), this study supports their proposition that some of the pair relationships indeed influence students' understanding of concepts. However,
although relationship can be built from the data and statistics, the nature of some relationships between similarity pairs and FCI items can not readily be explained. There may exist some implicit relationship, or the relation may be a product of sampling on measurement error.

Research question 3 asked whether students that share the same misconception have similar cognitive structure? This question was investigated by the mean difference variance of similarity ratings and similarity index of Pathfinder networks. For each FCI item, students were clustered into two groups according to their responses to the FCI question, correct response or the most high percentage incorrect response (which suggests one type of misconception). The variance for two groups' ratings on similarity pairs were compared. The results of the T-test on the mean difference variance (Table 13 and 14) show that, in most misconceptions, students with a specific misconception appear to have smaller variance on their ratings (although most differences are not significant), which means more congruent cognitive structures. However, comparison of two groups' sample Pathfinder networks (Table 15) shows that the group without a specific misconception has a larger within group similarity index than the group
with misconception \( p > .05 \); this means the correct group had more similar structures within group. In general, the results of this study fail to reject null hypothesis, so the proposition of Goldsmith et al. (1991), students that share the same misconception would also have similar structure, can not be supported. However, the contradictory and nonsignificance of the findings of this study may come from the vagueness of rating pairs discussed above; further study is needed to confirm it.

Research question 4 asked whether high performance students have structures similar to that of their teacher? Based on the T-test on the similarity index of different groups, high performance students' structures indeed are more similar to teachers than low performance students. This result is consistent with the studies of Chi, Feltovich and Glaser (1981), Chi and Koeske (1982), and Goldsmith et al. (1991).

Research question 5 asked whether the Pathfinder network provides hierarchical information that is implied implicitly in the raw data. Goldsmith et al. (1991) noted that one of the strengths of Pathfinder is that it can provide hierarchical networks if a hierarchical organization
exists in the data. Does this strength generalize to physics content such as mechanics?

The students' Pathfinder networks show some degree of hierarchy (star structure), however, the structures are not complete. The reason for incomplete hierarchical structure may come from students' misunderstanding of ratings pairs, students rate them differently because of the possible reasons discussed above.

Conclusion

The results of this study support the proposition that similarity ratings and Pathfinder network can be used to assess students' mechanics cognitive structure, although some problems may exist. Related studies on cognitive structures of different domains has supported the importance of further study on cognitive structures. Through the help of students' cognitive structures, the teachers can better understand the students' learning problems.

The study has also shown that misconceptions exist among high school students. Many students have substantial difficulties in learning science, misconception is one of the most important reasons (Reif & Larkin, 1991). If the
teacher can diagnose what misconceptions students have, then
instruction can be designed to enhance science learning.
Reliable techniques for finding a student's knowledge state
are critical.

In this study, results show that students at different
levels of performance have different cognitive structure,
high achievers' structure are more similar to teachers
according to the similarity index and closeness index. In
addition, relationships between concept pairs and
misconception were found in this study. This suggests
cognitive structure may be piloted in the classroom as an
alternative to performance evaluation.

Recommendations for Practice

Gorodetskt and Hoz (1985) noted that researches on
science teaching have shown that the learner's cognitive
structure plays an important role in both remembering the
learned material and learning new material.

For most students and teachers, classroom achievement
testing is a synonym of the evaluation of learning.
Although this kind of evaluation will continue to be
essential in the classroom, Novak and Gowin (1984) proposed
that a much wider range of practicable valuation methods are needed. This study and other related studies show that a relationship exists between students' cognitive structures and achievement. Consequently, assessing cognitive structure can play a role in the teaching style and the evaluation of students' progress. Teachers need to be trained in techniques of assessing cognitive structure before it can be implemented in the classroom.

As in this research, some concepts in content/teachers' structure have close interrelationships, e.g., constant force, free fall, and constant acceleration motion build a triangle structure in content/teachers' PFnet. However, students' cognitive structures do not show the structure, which may mean students lack knowledge about interrelationships among these concepts. If teachers can access the information, then the instruction (or remediation) can be focused on these concepts, through discussion or other teaching methods, students may understand these concepts better.
Recommendations for Further Study

This study has found the reliability of FCI increases when some items are excluded; further study is recommended to understand the significance of the increase.

The similarity ratings task in physics is difficult because physics concept pairs can have different degree of relationships in different environments. If condition or environment can be provided in the similarity ratings task, the students' rating data may be more reliable. In addition, further study can be done to check whether the rating data can be more reliable if several related concepts (a concept subset) are presented to students at the same time and then ask students to rate the relationships of all concepts in the subset. Moreover, the concepts used in the similarity ratings task must be carefully considered so they can represent the underlying concepts used in the diagnostic question.

In addition, this study finds only some similarity pairs have predictive ability to FCI items. Goldsmith et al. (1991) noted that "predictiveness is primarily a function of the number of concepts used in the assessment, and once a sufficient number of concepts is selected, the
predictions are quite stable across different classes of students" (p. 94). Further study is necessary to validate the appropriate subsets of concept pairs for specific content in assessing students' learning.

Some relationships between similarity ratings pairs and FCI items are not easily explained, further qualitative study including student interviews for probing their thinking related to the pairs and FCI items may help explain the relationships. In addition, further study of cognitive structures derived from interviews may help validate the outcomes from similarity ratings and Pathfinder algorithm.

In the long run, misconception diagnostic instrument need to be developed or modified so the items can have a better match with similarity concepts pairs. The relationship between misconceptions and concepts pairs then can be obtained affirmatively and may be useful for assessing learning. In addition, how the computer can be applied to extract students' cognitive structures and serve as student models in the development of intelligent CAI could be another long term study goal.
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Koubek, R. J., & Mountjoy, D. N. (1991). Toward a model of knowledge structure and a comparative analysis of knowledge structure measurement techniques. Wright State University, Dayton, OH.


APPENDIX A

CALCULATION OF SIMILARITY
AND
Closeness Index
Calculation of Similarity

The similarity between two networks is determined by the correspondence of links in the two networks. The similarity index is defined as the number of the links in common divided by the number of links that are not shared by both networks.

\[
\text{similarity} = \frac{\text{common links}}{(\text{net 1's links} + \text{net 2's links} - \text{common links})}
\]

Two identical networks will yield a similarity of 1, and two networks that share no links will yield similarity of 0. The measure is the proportion of all the links in either network that are in both networks. It can be calculated by KNOT program.

For example, the links of content/teachers' network (Figure 5), high achievers' network (Figure 6), and their common links are shown in Table 17. The similarity of the two networks is

\[
\text{similarity} = \frac{13}{(18+28-13)} = 0.394
\]
Table 17

Links of Content/Teachers' Network and High Achievers' Network

<table>
<thead>
<tr>
<th></th>
<th>Content</th>
<th>High Achievers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content</td>
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<td></td>
</tr>
<tr>
<td>High Achievers</td>
<td>13</td>
<td>18</td>
</tr>
</tbody>
</table>

Calculation of Closeness index

The Closeness (C) index is used to represent network similarity. The C index is calculated from the network configuration. Its values can be zero, which means two networks are completely different, through one, which means two networks are identical.

The algorithm for calculating C index (Michael, 1994) is:

1. For each concept in the network, the neighborhood set is identified. This set contains all concepts that are linked directly to the concept.
2. For each concept, the concept's intersection set, which represents the concepts that are common to both neighborhood sets in the two networks, is identified. The size of the
interaction set is the number of common elements in the two neighborhood sets of the concept in the two networks.

(3) For each concept, the union set and size (the total number of unique concepts in the union set) are identified. The union set represents all concepts in the two neighbor sets.

(4) For each concept, the ratio of the size of intersection set to the size of union set is calculated. The mean of all these ratios is the C index.

The values of C index can be from zero to one. Values that are equal to or close to zero indicate no or little similarity between two networks; the bigger the C index, means the more similarity between two networks.

Content/teachers’ network (Figure 5) and high achievers’ network (Figure 6) are used here to describe the calculation of C index. In order to make the calculation clear, the nineteen concepts are represented by numbers as follow:

1. force
2. velocity
3. acceleration
4. mass
5. weight
6. action
7. reaction
8. normal force
9. air pressure
10. friction
11. constant force
12. pull
11. constant force
12. pull
13. tension
14. increasing force
15. constant velocity
16. free fall
17. projectile motion
18. constant acceleration motion
19. decreasing force

The calculation done by calculator is represented in Table 18.
Figure 5. Pathfinder network of content/teachers' structure
Figure 6. Pathfinder network of high achievers' structure
### Table 18

Calculation of C Index for Two PFnets

<table>
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<tr>
<th>Concept</th>
<th>Content_net</th>
<th>High_net</th>
<th>Neighborhood set</th>
<th>Interaction set</th>
<th>Union set</th>
<th>Size</th>
<th>Quotient</th>
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Sum = 7.52

C index = 7.52/19 = 0.396
APPENDIX B

FORCE CONCEPT INVENTORY (FCI)
Force Concept Inventory

1. Two metal balls are the same size, but one weighs twice as much as the other. The balls are dropped from the top of a two story building at the same instant of time. The time it takes the balls to reach the ground below will be:

(A) about half as long for the heavier ball.
(B) about half as long for the lighter ball.
(C) about the same time for both balls
(D) considerably less for the heavier ball, but not necessarily half as long.
(E) considerably less for the lighter ball, but not necessarily half as long.

2. Imagine a head-on collision between a large truck and a small compact car. During the collision,

(A) the truck exerts a greater amount of force on the car than the car exerts on the truck.
(B) the car exerts a greater amount of force on the truck than the truck exerts on the car.
(C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
(D) the truck exerts a force on the car but the car doesn't exert a force on the truck.
(E) the truck exerts the same amount of force on the car as the car exerts on the truck.

3. Two steel balls, one of which weighs twice as much as the other, roll off a horizontal table with the same speed. In this situation:

(A) both balls impact the floor at approximately the same horizontal distance from the base of the table.
(B) the heavier ball impacts the floor at about half the horizontal distance from the base of the table that does the lighter.
(C) the lighter ball impacts the floor at about half the horizontal distance from the base of the table than does the heavier.
(D) the heavier ball hits considerably closer to the base of the table than the lighter, but not necessarily half the horizontal distance.
(E) the lighter ball hits considerably closer to the base of the table than the heavier, but not necessarily half the horizontal distance.

4. A heavy ball is attached to a string and swung in a circular path in a horizontal plane as illustrated in the diagram to the right. At the point indicated in the diagram, the string suddenly breaks at the ball. If these events were observed from directly above, indicate the path of the ball after the string breaks.

5. A boy throws a steel ball straight up. Disregarding any effects of air resistance, the force(s) acting on the ball until it returns to the ground is (are):

(A) its weight vertically downward along with a steadily decreasing upward force.
(B) a steadily decreasing upward force from the moment it leaves the hand until it reaches its highest point beyond which there is a steadily increasing force of gravity as the object gets closer to the earth.
(C) a constant downward force of gravity along with an upward force that steadily decreased until the ball reaches its highest point, after which there is only the constant downward force of gravity.
(D) a constant downward force of gravity only.
(E) none of the above, the ball falls down to the earth simply because that is its natural action.

Use the statement and diagram below to answer the next four questions:
The diagram depicts a hockey puck sliding, with a constant velocity, from point "a" to point "b" along a frictionless horizontal surface. When the puck reaches point "b", it received an instantaneous horizontal "kick" in the direction of the heavy print arrow.
6. Along which of the paths below will the hockey puck move after receiving the "kick"?

(A) 

(B) 

(C) 

(D) 

(E) 

7. The speeds of the puck just after it receives the "kick"?

(A) Equal to the speed "Vo" it had before it received the "kick".
(B) Equal to the speed "V" it acquires from the "kick" and independent of the speed "Vo".
(C) Equal to the arithmetic sum of speeds "Vo" and "V".
(D) Smaller the either of the speed "V" or "Vo".
(E) Greater than either of speeds "Vo" or "V", but smaller than the arithmetic sum of these two speeds.

8. Along the frictionless path you have chosen, how does the speed of the puck vary after receiving the "kick"?

(A) No change.
(B) Continuously increasing.
(C) Continuously decreasing.
(D) Increasing for a while, and decreasing thereafter.
(E) Constant for a while, and decreasing thereafter.

9. The main forces acting, after the "kick", on the puck along the path you have chosen are:

(A) the downward force due to gravity and the effect of air pressure.
(B) the downward force of gravity and the horizontal force of momentum in the direction of motion.
(C) the downward force of gravity, the upward force exerted by the table, and a horizontal force acting on the puck in the direction of motion.
(D) the downward force of gravity and an upward force exerted on the puck by the table.
(E) gravity does not exert a force on the puck, it falls because of the intrinsic tendency of the object to fall to its natural place.
10. The accompanying diagram depicts a semicircular channel that has been securely attached, in a horizontal plane, to a table top. A ball enters the channel at "1" and exits at "2". Which of the path representations would most nearly correspond to the path of the ball as if it exits the channel at "2" and rolls across the table top.

- Two students, student "a" who has a mass of 95 kg and student "b" has a mass of 77 kg sit in identical office chairs facing each other. Student "a" places his bare feet on student "b"'s knees, as shown below. Student "a" then suddenly pushes outward with his feet, causing both chairs to move.

11. In this situation,

(A) neither student exerts a force on the other.
(B) student "a" exerts a force on "b", but "b" doesn't exert any force on "a".
(C) each student exerts a force on the other but "b" exerts the larger force.
(D) each student exerts a force on the other but "a" exerts the larger force.
(D) each student exerts the same amount of force on the other.

12. A book is at rest on a table top. Which of the following force(s) is(are) acting on the book?

1. A downward force due to gravity.
2. The upward force by the table.
3. A net downward force due to air pressure.
4. A net upward force due to air pressure.

(A) 1 only
(B) 1 and 2
(C) 1, 2 and 3
(D) 1, 2 and 4
none of these, since the book is at rest there are no forces acting on it.

- Refer to the following statement and diagram while answering the next two questions.

A large truck breaks down out on the road and receives a push back into town by a small compact car.

13. While the car, still pushing the truck, is speeding up to get up to cruising speed;

(A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
(B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
(C) the amount of force of the car pushing against the truck is greater than that of the truck pushing back against the car.
(D) the car's engines is running so it applies a force as it pushes against the truck but the truck's engine is not running so it can't push against the car, the truck is pushed forward simply because it is in the way of the car.
(E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

14. After the person in the car, while pushing the truck, reaches the cruising speed at which he/she wishes to continue to travel at a constant speed;

(A) the amount of force of the car pushing against the truck is equal to that of the truck pushing back against the car.
(B) the amount of force of the car pushing against the truck is less than that of the truck pushing back against the car.
(C) the amount of force of the car pushing against the truck is greater than that of the truck pushing back against the car.
(D) the car's engines is running so it applies a force as it pushes against the truck but the truck's engine is not running so it can't push against the truck is pushed forward simply because it is in the way of the car.
car, the truck is pushed forward simply because it is in the way of the car.
(E) neither the car nor the truck exert any force on the other, the truck is pushed forward simply because it is in the way of the car.

15. When a rubber ball dropped from rest bounces off the floor, its direction of motion is reversed because;

(A) energy of the ball is conserved.
(B) momentum of the ball is conserved.
(C) the floor exerts a force on the ball that stops its fall and then drives it upward.
(D) the floor is in the way and the ball has to keep moving.
(E) none of the above.

16. Which of the paths in the diagram to the right best represents the path of the cannon ball?

17. A stone falling from the roof of a single story building to the surface of the earth;

(A) reaches its maximum speed quite soon after release and then falls at a constant speed thereafter.
(B) speeds up as it falls, primarily because the closer the stone gets to the earth, the stronger the gravitational attraction.
(C) speeds up because of the constant gravitational forces acting on it.
(D) falls because of the intrinsic tendency of all objects to fall toward the earth.
(E) falls because of a combination of the force of gravity and the air pressure pushing it downward.

• When responding to the following question, assume that any frictional forces due to air resistance are so small that they can be ignored.
18. An elevator, as illustrated, is being lifted up an elevator shaft by a steel cable. When the elevator is moving up the shaft at a constant velocity:

(A) the upward force on the elevator by the cable is greater than downward force of gravity.
(B) the amount of upward force on the elevator by the cable equal to that of the downward force of gravity.
(C) the upward force on the elevator by the cable is less than the downward force of gravity.
(D) it goes up because the cable is being shortened, not because of the force being exerted on the elevator by the cable.
(E) the upward force on the elevator by the cable is greater than the downward force due to the combined effects of air pressure and the force of gravity.

19. A golf ball driven down a fairway is observed to travel through the air with a trajectory (flight path) similar to that in the depiction below.

which following force(s) is(are) acting on the golf ball during its entire flight?

1. the force of gravity
2. the force of the "hit"
3. the force of air resistance

(A) 1 only  (D) 1 and 3
(B) 1 and 2  (E) 2 and 3
(C) 1, 2, and 3

20. A bowling ball accidentally falls out of the cargo bay of an airliner as it flies along in a horizontal direction. As seen from the ground,
which path would the bowling ball most closely follow after leaving the airplane?

- When answering the next four questions, refer to the following statement and diagram.

A rocket, drifting sideways in outer space from position "a" to position "b", is subject to no outside force. At "b", the rocket's engine starts to produce a constant thrust at right angles to line "ab". The engine turns off again as the rocket reaches some point "c".

21. Which path below best represents the path of the rocket between "b" and "c"?

22. As the rocket moves from "b" to "c", its speed is
(A) constant.
(B) continuously increasing.
(C) continuously decreasing.
(D) increasing for a while and constant thereafter.
(E) constant for a while and decreasing thereafter.

23. At "c" the rocket's engine is turned off. Which of the paths below will the rocket follow beyond "c"?
24. Beyond "c", the speed of the rocket is:

(A) constant.
(B) continuously increasing.
(C) continuously decreasing.
(D) increasing for a while and constant thereafter.
(E) constant for a while and decreasing thereafter.

25. A large box is being pushed across the floor at a constant speed of 4.0 m/s. What can you conclude about the force acting on the box?

(A) If the force applied to the box is doubled, the constant speed of the box will increase to 8.0 m/s.
(B) The amount of force applied to move the box at a constant speed must be more than its weight.
(C) The amount of force applied to move the box at a constant speed must be equal to the amount of the frictional forces that resist its motion.
(D) The amount of force applied to move the box at a constant speed must be more than the amount of the frictional forces that resist its motion.
(E) There is a force being applied to the box to make it move but the external forces such as friction are not "real" forces they just resist motion.

26. If the force being applied to the box in the preceding problem is suddenly discontinued, the box will

(A) stop immediately.
(B) continue at a constant speed for a very short period of time and then slow to a stop.
(C) immediately start slowing to a stop.
(D) continue at a constant velocity.
(E) increase its speed for a very short period of time, then start slowing to a stop.

Note. The Force Concept Inventory (FCI) was developed by Hestenes et al. (1992), the total items were 29. In this study, three items (18,19,20) were excluded because they were not very related to the research topic. The item numbers are renumbered in this instrument.
353

(8) 水浮力$A$为作用于$A$的等效重力，其表达式为

$$\text{水浮力} = A \times g$$

(9) $A$和$O$的等效重力，表达式为

$$\text{等效重力} = A \times g + O \times g$$

(10) $A$和$O$的等效重力与其他因素的关系

【图片】

(6) 浮力对整体物的浮力，其等效重力为

【图片】

(7) 浮力对整体物的等效重力，其等效重力为

【图片】

(8) $A$和$O$的等效重力，其表达式为

$$\text{等效重力} = A \times g + O \times g$$

(9) $A$和$O$的等效重力与其他因素的关系

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(10) $A$和$O$的等效重力与其他因素的关系

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(11) $A$和$O$的等效重力与其他因素的关系

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(100) $A$和$O$的等效重力与其他因素的关系

【图片】
(9) 在水平瞬間力作用後，球受那些力量作用
(A) 往下的重力及空氣壓力
(B) 往下的重力及沿著運動方向的水平力?
(C) 往下的重力，地面施給的往上力量，及沿著運動方向的水平力
(D) 往下的重力，地面施給的往上力量
(E) 重力沒有對球產生作用，球往下掉是因爲物體有回到自然位置的本能

(10) 一半圓形的管子被固定於水平桌面上，
如右圖所示，一個小球從 1 端進入管中然後由 2 端滾出，問那一條軌跡能代表球離開管子後的運動路徑？

(11) 兩個學生互相面對著坐在有輪子椅子上，甲質量為 95 公斤，乙質量為 77 公斤，甲把他的腳放在乙的膝蓋上，如圖所示，若甲突然把腳伸直使兩張椅子向外移動，在此情況下
(A) 兩人都沒有施力於對方
(B) 甲施力給乙，但乙沒有施力給甲
(C) 兩人都有施力給對方，但乙施力較大
(D) 兩人都有施力給對方，但甲施力較大
(E) 兩人都施相同的力給對方

(12) 一本書放於桌上，問有哪些力作用於書上？
1. 往下的重力
2. 桌子往上的力
3. 空氣造成的往下浮力
4. 空氣造成的往上浮力

(A) 只有 1
(B) 1 和 2
(C) 1 2 和 3
(D) 1 2 和 4
(E) 以上皆非，因為書是靜止不動的，所以沒有任何力作用於它

請參考下列敘述及圖形回答下面兩題問題
一輛大卡車在路上故障拋矛，而由一輛小汽車從後面推著它前進
(16) 下面的观点都正确：

(A) 现代汽车的发动机性能已经非常强大，可以轻松地从静止状态加速到高速。
(B) 车速过快会增加交通事故的风险。
(C) 均速行驶是安全驾驶的关键。
(D) 使用安全带可以减少发生严重事故的概率。

(15) 车的其他方面

(3) 以下观点正确：

(A) 安全驾驶包括遵守交通规则。
(B) 车辆定期保养可以延长使用寿命。
(C) 驾驶时保持冷静很重要。
(D) 使用导航系统可以避免迷路。

(14) 车的其他方面

(2) 以下观点正确：

(A) 高速公路上应该保持安全距离。
(B) 在高速公路行驶时应避免频繁变道。
(C) 驾驶过程中应时刻注意前方路况。
(D) 使用手机在驾驶过程中是危险的。
(17) 一塊石頭從一樓頂掉落地面
(A) 石頭開使掉落後很快達到最大速度，然後以等速落下
(B) 石頭下落後開始加速，其原因是因為球愈靠近地面，所受的地心引力愈強
(C) 石頭下落後開始加速，主要是因為受到大小不變的重力作用
(D) 石頭掉落是因爲所有物體都有落向地面的本能
(E) 石頭掉落是因為重力及空氣壓力的一起作用

(18) 一電梯由鋼纜拉著以等速往上升，假設忽略摩擦力
(A) 鋼纜對電梯的往上拉力大於往下的重力
(B) 鋼纜對電梯的往上拉力等於往下的重力
(C) 鋼纜對電梯的往上拉力小於往下的重力
(D) 電梯往上升是因為鋼纜變短了，而不是因為鋼纜施力於電梯
(E) 鋼纜對電梯的往上拉力大於往下的重力
是因为空氣壓力與重力的混和作用

(19) 一高爾夫球被球桿擊出後以拋物線的路徑飛往目標區，
在高爾夫球飛行途中，有那些力量作用於它？
1. 重力
2. 球桿擊球之力
3. 空氣阻力
(A) 只有 1
(B) 1 和 2
(C) 1, 2 和 3
(D) 1 和 3
(E) 2 和 3

(20) 一架飛機正於水平方向飛行時，一個保齡球突然由貨艙掉落從，從地面上看，
那一條軌跡是保齡球落下的路徑：
參考以下敘述，回答後面四個問題：

- 太空船在外太空由位置 A 等速往右漂浮，沒有受任何外力作用。在抵達位置 B 時，太空船引擎啓動產生一垂直於線 AB 的力量，使太空船往方向 C 前進，當太空船到達位置 C 時引擎再次關掉。

(21)那一條軌跡是太空船由位置 B 到位置 C 的行進路徑？

(22)太空船由位置 B 行進到位置 C 的過程中，其速率是

(A) 等速
(B) 加速
(C) 減速
(D) 加速一段時間然後等速前進
(E) 等速前進一段時間然後減速

(23)在位置 C 時引擎關掉，那一條是太空船在位置 C 以後的行進路徑

(24)在位置 C 以後太空船的速率是：

(A) 等速
(B) 加速
(C) 減速
(D) 加速一段時間然後等速前進
(E) 等速前進一段時間然後減速
(25)一個大箱子在地面上被一外力推著以 4.0 公尺/秒的速度等速前進，作用於箱子的力量
(A) 如果作用於箱子的力量加倍，則箱子的速度會增為 8.0 公尺/秒。
(B) 作用於箱子使其以等速前進的力量必須大於箱子本身的重量
(C) 作用於箱子使其以等速前進的力量必須等於阻止其運動的摩擦力
(D) 作用於箱子使其以等速前進的力量必須大於阻止其運動的摩擦力
(E) 有一個力作用於箱子使其前進，但是外力像摩擦力不是真正力量，它
只是要阻止運動而已

(26)若上題中的力量突然不見了，這箱子會
(A) 立即停止運動
(B) 繼續以等速前進一小段時間，然後速度變慢至停止不動
(C) 速度立即減慢至停止不動
(D) 繼續以等速前進
(E) 加速前進一小段時間，然後速度變慢至停止不動
APPENDIX C

BOOKLET FOR SIMILARITY RATINGS
The purpose of this task is to judge the relatedness of pairs of concepts. There are many kinds of relationships that concepts may have. Your task is to make an overall judgment about how two concepts are related.

On the following pages, pairs of concepts are presented. In each case, one of the concepts is placed to the left of the ruler, the other one is temporarily on the top of the ruler. Place the second concept on the ruler at a distance to the right of the first concept so as to indicate how closely the two concepts are related. If the two concepts are closely related, they should be close together. If the two concepts are only slightly or not at all related, they should be far apart.

For example, the relationship of the concepts of tiger and lion might be represented as:

lion

tiger:----X:------:------:------:------:------:

or

lion

tiger:------:X------:------:------:------:------:

The relationship between cat and cup might be represented as:

cup

cat:------:------:------:------:------:------:------:-----:X---:

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or

\begin{align*}
\text{cup} \\
\text{cat:-----:-----:-----:-----:-----X-----:-----:-----:-----}
\end{align*}

Remember, the distance represents the relatedness of two concepts and is determined by your own experience and judgment. There is no absolute answer.

The concepts to be judged are:

\begin{align*}
\text{force} & \quad \text{velocity} & \quad \text{acceleration} & \quad \text{mass} & \quad \text{weight} \\
\text{action} & \quad \text{reaction} & \quad \text{normal force} & \quad \text{air pressure} \\
\text{friction} & \quad \text{constant force} & \quad \text{pull} & \quad \text{tension} \\
\text{increasing force} & \quad \text{constant velocity} & \quad \text{motion} \\
\text{free fall} & \quad \text{projectile motion} & \quad \text{decreasing force} \\
\text{constant acceleration} & \quad \text{motion}
\end{align*}

Before going to the next page, try to find a pair that you feel are very closely related and a pair that you feel are not related at all (or very weak related). Use these pairs as reference index to judge the relatedness of other pairs of concepts.

If you have any questions about the task, please ask the teacher at any time.
<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Notes</th>
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<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
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<td></td>
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<tr>
<td>3</td>
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<td>5</td>
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<td>6</td>
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<td></td>
</tr>
<tr>
<td>7</td>
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<tr>
<td>8</td>
<td>increasing force</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>weight</td>
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<tr>
<td>10</td>
<td>projectile motion</td>
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<tr>
<td>11</td>
<td>mass</td>
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<td>12</td>
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</tr>
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<td>13</td>
<td>friction</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>constant acceleration motion</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>action</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>constant force</td>
<td></td>
</tr>
</tbody>
</table>

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velocity
force:------:------:------:------:------:---:

velocity
mass:------:------:------:------:------:---:

action
normal force:------:------:------:------:------:---:

constant acceleration motion
friction:------:------:------:------:------:---:

free fall
air pressure:------:------:------:------:------:---:

friction
pull:------:------:------:------:------:---:

acceleration
force:------:------:------:------:------:---:

normal force
reaction:------:------:------:------:------:---:

friction
tension:------:------:------:------:------:---:

increasing force
projectile motion:------:------:------:------:------:---:

constant velocity motion
force:------:------:------:------:------:---:

projectile motion
decreasing force:------:------:------:------:------:---:

normal force
weight:------:------:------:------:------:---:

constant
free fall
velocity motion:------:------:------:------:------:---:

tension
force:------:------:------:------:------:---:

air pressure
velocity:------:------:------:------:------:---:---:
constant acceleration motion

free fall:------:------:------:------:------:------:

friction

action:------:------:------:------:------:------:

velocity

tension:------:------:------:------:------:------:

constant projectile motion

velocity motion:------:------:------:------:------:------:

weight

acceleration:------:------:------:------:------:------:

friction

decreasing force:------:------:------:------:------:------:

reaction

force:------:------:------:------:------:------:

action

velocity:------:------:------:------:------:------:

air pressure

projectile motion:------:------:------:------:------:------:

constant force

tension:------:------:------:------:------:------:

normal force

velocity:------:------:------:------:------:------:

projectile motion

normal force:------:------:------:------:------:------:

decreasing force

tension:------:------:------:------:------:------:

pull

action:------:------:------:------:------:------:

velocity

reaction:------:------:------:------:------:------:

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normal force:

free fall

air pressure

reaction:

tension

increasing force:

friction

reaction:

decreasing force

free fall:

constant acceleration motion

projectile motion:

action

acceleration:

reaction

pull:

weight

force:

mass

acceleration

reaction:

constant velocity motion

increasing force:

action

reaction:

free fall

friction:

constant velocity motion

friction:

acceleration

normal force:

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constant acceleration motion

decreasing force: ----:----:----:----:----:----:----:

air pressure

mass: ----:----:----:----:----:----:----:

action

weight: ----:----:----:----:----:----:----:

friction

normal force: ----:----:----:----:----:----:----:

constant velocity motion

constant force: ----:----:----:----:----:----:----:

reaction

normal force: ----:----:----:----:----:----:----:

constant force

weight: ----:----:----:----:----:----:----:

free fall

constant acceleration motion

pull: ----:----:----:----:----:----:----:

weight: ----:----:----:----:----:----:----:
概念關係判斷

這個工作的目的是判斷兩個概念之間的關係，概念之間可能有許多不同的關係存在，你（妳）的工作是做一個整體的判斷兩個概念之間的關係深淺。

在下面的表中每一個題目包含兩個概念，其中一個放在直尺的左端，另一個暫時擺在尺的上方。請將尺上方的概念放到尺上適當的位置，使其與左端的距離代表兩個概念的關係。如果兩個概念的關係很深，不論是什麼關係，則它們應靠近在一起；如果兩個概念沒什麼關係或毫無任何關係，則它們應互相遠離。

例如，老虎和獅子的關係可表示如下：

獅子
老虎：----X:------:------:------:------:------:------:------:

或

獅子
老虎：------:X------:------:------:------:------:------:

貓和杯子的關係可表示如下

杯子
貓：--------:-------:--------:--------:--------:--------:------:

或

杯子
貓：--------:-------:--------:--------:--------:--------:X------:

"X" 代表尺上方的概念在尺上的位置。記住，兩者之間的距離代表它們關係的深淺，這個關係的判斷完全根據你（妳）自己的經驗與看法，並沒有標準答案也沒有對錯可言。

要被判斷關係的概念如下：

力  速度  等加速度  質量  重量  作用力
反作用力  正向力  空氣壓力  摩擦力  定力  拉力
張力  逐漸增大的力  等速度運動  自由落體
拋體運動  逐漸減小的力  等加速度運動

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在正式開始判斷前，請先嘗試從上列概念中找出一對關係很深的概念，及一對沒有什麼關係的概念，做為判斷其它關係的參考。然後根據這兩個標準來決定其他各對概念的距離。

如有任何問題請隨時請問老師。（注：在考慮各種運動時，假設各種運動都發生在很靠近地球表面的地方）

*請將尺上方的概念擺在適當的位置*

速度
加速度：--------:--------:--------:--------:--------:--------:--------:

摩擦力
速度：--------:--------:--------:--------:--------:--------:--------:

自由落體
力：--------:--------:--------:--------:--------:--------:--------:

速度
重量：--------:--------:--------:--------:--------:--------:--------:

力
質量：--------:--------:--------:--------:--------:--------:--------:

等加速度運動
定力：--------:--------:--------:--------:--------:--------:--------:

質量
摩擦力：--------:--------:--------:--------:--------:--------:--------:

逐漸增大的力
摩擦力：--------:--------:--------:--------:--------:--------:--------:

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重量
摩擦力: ..............................

拋體運動
定力: ..............................

質量
重量: ..............................

自由落體
逐漸增大的力: ..............................

摩擦力
定力: ..............................

等加速度運動
逐漸增大的力: ..............................

作用力
張力: ..............................

定力
自由落體: ..............................

速度
力: ..............................

速度
質量: ..............................
作用力
正向力：

等加速度運動
摩擦力：

自由落體
空氣壓力：
摩擦力
拉力：

加速度
力：

正向力
反作用力：

摩擦力
張力：

逐漸增大的力
拋體運動：

等速度運動
力：

拋體運動
逐漸減小的力：
正向力
重量:----:----:----:----:----:----:----:----::

自由落體
等速度運動:----:----:----:----:----:----:----:----::

張力
力:----:----:----:----:----:----:----:----::

空氣壓力
速度:----:----:----:----:----:----:----:----::

等加速度運動
自由落體:----:----:----:----:----:----:----:----::

摩擦力
作用力:----:----:----:----:----:----:----:----::

速度
張力:----:----:----:----:----:----:----:----::

拋體運動
等速度運動:----:----:----:----:----:----:----:----::

重量
加速度:----:----:----:----:----:----:----:----::

摩擦力
逐漸減小的力:----:----:----:----:----:----:----:----::
反作用力
力: ---------:---------:---------:---------:---------:---------:

作用力
速度: ---------:---------:---------:---------:---------:---------:

空氣壓力
拋體運動: ---------:---------:---------:---------:---------:---------:

定力
張力: ---------:---------:---------:---------:---------:---------:

正向力
速度: ---------:---------:---------:---------:---------:---------:

拋體運動
正向力: ---------:---------:---------:---------:---------:---------:

逐漸減小的力
張力: ---------:---------:---------:---------:---------:---------:

拉力
作用力: ---------:---------:---------:---------:---------:---------:

速度
反作用力: ---------:---------:---------:---------:---------:---------:

自由落體
正向力: ---------:---------:---------:---------:---------:---------:

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空氣壓力
反作用力: ----------:----------:----------:----------:----------:----------:

張力
逐漸增大的力: ----------:----------:----------:----------:----------:----------:

摩擦力
反作用力: ----------:----------:----------:----------:----------:----------:

逐漸減小的力
自由落體: ----------:----------:----------:----------:----------:----------:

等加速度運動
拋體運動: ----------:----------:----------:----------:----------:----------:

作用力
加速度: ----------:----------:----------:----------:----------:----------:

反作用力
拉力: ----------:----------:----------:----------:----------:----------:

重量
力: ----------:----------:----------:----------:----------:----------:

質量
加速度: ----------:----------:----------:----------:----------:----------:

加速度
反作用力: ----------:----------:----------:----------:----------:----------:

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等速度運動
逐漸增大的力：

作用力
反作用力：

自由落體
摩擦力：

等速度運動
摩擦力：

加速度
正向力：

力
作用力：

空氣壓力
加速度：

張力
反作用力：

摩擦力
加速度：

質量
反作用力：
加速度
張力：---------:---------:---------:---------:---------:---------:---------:

作用力
質量：---------:---------:---------:---------:---------:---------:---------:

逐漸減小的力
等速度運動：---------:---------:---------:---------:---------:---------:---------:

正向力
空氣壓力：---------:---------:---------:---------:---------:---------:---------:

張力
拉力：---------:---------:---------:---------:---------:---------:---------:

空氣壓力
等加速度運動：---------:---------:---------:---------:---------:---------:---------:

正向力
質量：---------:---------:---------:---------:---------:---------:---------:

空氣壓力
摩擦力：---------:---------:---------:---------:---------:---------:---------:

等速度運動
空氣壓力：---------:---------:---------:---------:---------:---------:---------:

等速度運動
拉力：---------:---------:---------:---------:---------:---------:---------:

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等加速度運動
逐漸減小的力:

空氣壓力
質量:

作用力
重量:

摩擦力
正向力:

等速度運動
定力:

定力
正向力:

反作用力
重量:

等加速度運動
拉力:

自由落體
重量:
APPENDIX D

EXAMPLE OF PROXIMITY MATRIX AND PATHFINDER ALGORITHM
Pathfinder networks are configurations in which concepts (objects, events, actions, or entities) are represented as nodes and relationships are represented as links connecting the nodes. The links have values representing the strength of the relationship between the concepts in terms of the distance between nodes (Dearholt & Schvaneveldt, 1990).

Pathfinder networks are derived from proximity matrix data. Each concept in the matrix is represented as a node and the proximities represent how closely the nodes are linked. Not every node in the network is necessarily linked to every other node. A link between two nodes is added if distance of this direct link is less than the distance of all possible indirect paths between these two nodes (Branaghan, 1990). Therefore, "Pathfinder extracts the latent structure in the data" (Jonassen et al., 1993, p. 73).

A set of hypothetical proximity data for five concepts (A, B, C, D and E) and its resulting Pathfinder network are shown in Figure 7. The number in the proximity matrix represents the distance (low number means close or strong relationship) between the corresponding two concepts. The corresponding Pathfinder network is on the right side. The links between nodes represent the distances. Among them,
the direct links between A and C (distance is 3), B and D (distance is 4), B and E (distance is 6), C and D (distance is 5), C and E (distance is 5), D and E (distance is 4) are excluded because an indirect path exists between each pair of concepts, and the indirect path has a distance that is less or equal distance as the direct link of the pair. For example, an indirect path connects A and C through B, the total distance of the path (which is the sum of the distance between A and B, B and C) is 2, while the direct distance between A and C is 3 that is greater than the indirect distance, therefore the direct link between A and C is ignored.

Proximity Data

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<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
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</tr>
<tr>
<td>C</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
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<td></td>
</tr>
<tr>
<td>E</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>4</td>
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</tr>
</tbody>
</table>

Pathfinder Network

Figure 7. A set of hypothetical proximity data and its resulting Pathfinder network