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Structural Assessment of Knowledge for Misconceptions in the Domain of Physics

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STRUCTURAL ASSESSMENT OF KNOWLEDGE FOR MISCONCEPTIONS IN THE DOMAIN OF PHYSICS

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University of Ottawa, in partial fulfilment of the requirements for
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ABSTRACT

Unlike textual description, pathfinder network (an algorithm that results in a kind of concept map) provides a visual way to describe the knowledge structure of a student. It often provides a clear measure of the student's understanding and highlights the student's misconceptions. The traditional approaches of assessment such as multiple-choice questions and word problems often fail to identify these misconceptions. The following steps were carried out for this study.

1. The study assessed the knowledge structures of grade 11 physics students of a public high school of Ottawa and their instructor using *pathfinder* networks. The *work concept* (a subset of links around the concept of *work*) in the students' pathfinder networks was compared to the work concept in the referent network and the similarity between them was calculated.
2. During the intervention phase of the study, individualized instructions and exercises based on the misconceptions about the concept of work, shown by their knowledge structures, were given to the students.
3. The study again assessed the knowledge structures of the students for a change in work concept in their pathfinder networks by comparing it with the referent network. The study also analyzed the control concepts of "mass" and "gravity" in the pathfinder networks of the students and found no significant change in those.

In addition to pathfinder networks' utility as a global measure of conceptual knowledge of the students, which is useful for summative assessment, this research is a step forward to provide evidence that an individual node in the pathfinder network can be explored to study a particular concept in the network. Therefore, the research demonstrates the potential utility of pathfinder networks for formative assessment. This offers the possibility of providing the students with extremely comprehensive feedback.

Results revealed that the similarity index of work concept in the pathfinder networks of the students increased from pre- to post-intervention phase. Most likely, the major reason for this change was that individualized instructions were given to each student about the concept of work which stimulated and probably changed some of their misconceptions. To address validity, the similarity indices of mass and gravity concepts in the pathfinder networks of the students were also checked for improvement. The result shows that there is no significant improvement in mass and gravity concepts as the individualised instructions were not given to the students about mass and gravity concepts. Findings support the use of structural assessment of knowledge with pathfinder scaling technique for formative assessment as a way to enhance learning.

CONTENTS

CHAPTER 1: INTRODUCTION

DEFINITION AND REVIEW OF THE TERM MISCONCEPTION

Students always bring *prior knowledge* to their learning experiences which sometimes leads them to idiosyncratic interpretations of real world events (Anderson & Nashon, 2007). That prior knowledge also greatly affects how students understand, encode and later retrieve new information (Hailikari, Nevgi, & Lindblom-Ylänne, 2007). As new knowledge is made available to students, it is essential to link it with the knowledge students already have. These connections foster integration and interconnections between ideas (Blumenfeld, Marx, Patrick, Krajcik, & Soloway, 1997) and allow students to retrieve information later (Anderson, 1995). The knowledge initially available to a student also constrains what the student can learn from instructions given by a teacher. DiCerbo (2007) observes that "the most important single factor influencing learning is what the learner already knows" (p. 264).

Often the ideas that students carry with them in the domain of science are different from scientists' (Costu & Ayas, 2005; Michael, 1998; Bishop & Anderson, 1990). Osborne and Wittrock (1983) reviewed the research on student conceptions and stated briefly in their statement that "children develop ideas about their world, develop meanings for words used in science, and develop strategies to obtain explanations for how and why things behave as they do" (p. 491). These beliefs, theories, meanings, and explanations of children form the basis of the term *student conceptions.* Some other researchers use different terms to explain these beliefs of students, including the following: children's science (Osborne & Freyberg, 1985), preconceptions (Ausubel, Novak, & Hanesian, 1978), naïve theories (Resnick, 1983), conceptual primitives (Clement, 1982), private concepts (Sutton, 1980), and alternative frameworks (Driver, 1981). When those conceptions are seen to be in conflict with the accepted meanings in science, the term *misconceptions* (Nesher, 1987; Perkins & Simmons, 1988) is often used. Although the connotation of "misconception" is negative, it still represents an effort by a learner to form and organize the ideas to understand the world around him/her. The success of these efforts will depend both on the developmental stage of a learner and exposure of a learner to new experiences and new knowledge.

Pines (1985) analyzed the importance of meaningful relation and variation in conceptual understandings and expressed that the "concepts, on the one hand, are capable of change, and, on the other hand, can never be acquired in any finalistic fashion. Any new relations will affect, to some extent, the total framework of relations" (p. 110). This allows him to make a definition of a misconception within conceptual structures as viewed across time and circumstance. According to Pines (1985),

> Certain conceptual relations that are acquired may be inappropriate within a certain context. We term such relations as *misconceptions*. A misconception does not exist independently, but is contingent upon a certain existing conceptual framework. As conceptual frameworks change, what was deemed a misconception may no longer be a misconception; conversely, what is a central conceptual relationship in one framework may be a profound misconception within another framework. The history of science is replete with such examples. (p. 110)

Hammer (1996) defines misconceptions by these four properties:

1. Misconceptions are strongly held and are represented in stable cognitive structures;
2. Misconceptions differ from expert's conceptions (an expert is a person with extensive knowledge or ability in a particular area of study);
3. Misconceptions affect students' understanding of natural phenomena and scientific explanations; and

4. Misconceptions must be overcome, avoided, or eliminated for students to achieve expert understanding.

Physics is one of the domains where students have many misconceptions. I taught physics at the college level for 12 years and observed many misconceptions among my students regarding their conceptual organization in physics. For example, many students think that heavier objects fall faster (Halloun & Hestenes, 1985) and friction depends on the area in contact as a rounded ball is easy to move from one place to another as compared to a rectangular sheet (Singh, 2007). Some other common examples of misconceptions in physics are:

1. Force of the hand acting on a coin tossed in the air. Force is considered by many novices to be a property of moving objects.
2. Bigger objects exert larger forces on lighter objects when they interact.
3. Blocking the top half of a lens while an image is formed results in only half the image.

HOW DO STUDENTS DEVELOP MISCONCEPTIONS?

Misconceptions are usually acquired during the young age to construct a way of making sense of an unfamiliar and complex world. In science there are cases in which a student's prior knowledge and beliefs about something do not match what is known to be scientifically correct. The problem with misconceptions is that they often affect the understanding of physical phenomenon during the process of formal learning. Students may come to school with many misconceptions about how things work. Misconceptions are ideas that are most likely formed by a student's daily experiences including, but not limited to, information gained from parents, siblings, friends, or even television, movies and internet. Since these misconceptions are constructed by the student himself and have inherent validity with the student, and the ideas have not been previously challenged, they may be very hard to change (Hameed, Hackling, & Garnett, 1993; Baser & Geban, 2007). Some students even do not like to be proven wrong and continue possessing a misconception even in the face of evidence to the contrary (Brown & Clement, 1987). Other factors can be the lack of background knowledge or the lack of will to re-evaluate information.

Misconceptions develop in a variety of ways. Often misconceptions are passed on by one student to the next. In other cases, students may learn two correct concepts in the classroom, but may combine or confuse them. Sometimes students make, what seems to them, a logical conclusion, but is simply drawn from too little evidence or lack of experience. One of the most common sources of misconceptions is the fact that meanings of words in our everyday language may be contradictory to their scientific terms. For example, the term *elasticity* has one meaning in a lay conversation ("the stretchier the more elastic") and an exactly opposite meaning in physics ("the greater the restoring force the great the elasticity"). As a consequence, students working with the first definition develop serious misconceptions. The definition of the term *work* (work = force × displacement) also does not correspond to the colloquial usage of the term. Therefore, the term sometimes becomes confusing. For example, a person holding a heavy weight at rest in the air may say that he is doing hard work—and he may work hard in the physiological sense—but from the physics point of view, he is not doing any work. This is because the applied force causes no displacement (Halliday, Resnick, & Walker, 2005). Misconceptions are also culture-free. Yeo and Zadnik (2001) reported in their study that misconceptions in heat and temperature are common among students independent of their age and cultural group. For instance, Turkish people use heat and temperature interchangeably as do English people (BBC, 2008, July 11).

Vygotsky highlights the different ways in which every day (spontaneous) and scientific (academic) concepts are developed and related. Everyday concepts develop from daily life incidents and consequently depend on reference points and context. Scientific concepts are defined in relation to each other and are interconnected through an integrated network. The difficulty in learning and understanding these scientific concepts lies in their abstractness and detachment from reality. The process of learning, therefore, depends upon schemas a student already has. These scientific concepts cannot be acquired "directly", by means of mere memorization. Vygotsky (1997) argues: "Direct teaching of concepts is impossible and fruitless. A teacher who tries to do this usually accomplishes nothing but empty verbalism, a parrot-like repetition of words by the child, simulating a knowledge of the corresponding concepts but actually covering up a vacuum" (p. 150). If scientific concepts are not associated with practical examples in the classroom, then students are unable to understand these abstract concepts. Misconceptions are developed when students integrate new information, learned at school, with their prior knowledge resulting in the new knowledge being reinterpreted to correspond with everyday experiences (Vosniadou, 1994). Vygotsky (1997) referred to these conceptions as pseudo-concepts; when learners use words they have heard from adults, but with a different logical structure.

MENTAL MODELS AND EPISTEMOLOGIES OF STUDENTS HAVING MISCONCEPTIONS

Students with misconceptions construct different mental models (*mental model* represents what students think about a particular concept) by which they explain concepts and processes happening around them; indeed, they do so already as young children and before receiving formal instruction on those concepts (Carey, 1985). These mental models usually contain misconceptions that are far from the scientifically correct ideas (Diakidoy, Vosniadou, & Hawks, 1997). Many students have difficulty in changing their misconceptions because these false concepts may be deeply ingrained in the mental map of students or they are committed to their existing knowledge (Reiner, Slotta, Chi, & Resnick, 2000). However, there is also an ongoing debate about the knowledge structure of a student: To what degree does student's knowledge structure has a "theory-like" organization, as opposed to a fragmented knowledge structure? McCloskey (1983) argued that "people develop on the basis of their everyday experience remarkably well-articulated naïve theories" (p. 301). Au (1994) suggested that even children as young as 3 or 4 years of age develop a conceptual framework for understanding and exhibit a well-defined, theory-like knowledge of substances. The difference in the context and amount of experience may govern the extent to which naïve concepts are organized in a theory-like structure. These findings suggest that children's ideas form a rather coherent knowledge structure.

The conceptual change approaches of Ausubel (1963, 1968) and later of Novak (1985) marked the beginning of the most active period of research on misconceptions and alternative conceptions. Ausubel distinguished between *meaningful* and *rote* learning. He rejected the verbatim repetition of definitions and the reproduction of procedures and specified the conditions for meaningful learning: appropriate materials, the motivation of the student to relate old and new ideas, and preconceptions, which encourage the student to revisit his preconceptions. Ausubel saw cognitive structure as hierarchically organized. He used the terms *subsumption,* the use of general concepts to acquire and organize new concepts; *progressive differentiation,* in which new links are formed among related concepts; and *integrative reconciliation,* in which a learner relates previously held concepts to resolve conflicts in meanings. This proposition of Ausubel makes it more important to examine "what a student already knows".

Clement's studies provide a classic example of research on misconceptions in the early phase. Clement (1987b) suggested that misconceptions might provide a good starting point for instructions and that a theoretically consistent model can be approached by means of bridging analogies. The approach of giving individualized instructions to the students in this study is, therefore, situated in the context of the research conducted by Clement (1987a, 1987b, 1989) in the area of students' misconceptions of physics knowledge. Clement conducted a tutorial in which he tried to bridge the gap between examples already known to students, what he called *anchoring examples*, to illustrate certain law or principle and the *target examples* which the students do not perceive but impart the same idea. The *bridging examples* were used as supports in conceptually bringing the two analogous examples closer together. To explain further, consider the common misconception, contrary to Newton's third law of motion, that a table does not exert a force on a book lying on it even though students understand that the book exerts a force on the table. The anchoring example which could activate the correct schema would be to ask students to use their hand to push down on a spring. When students would exert a force downward on the spring, they could also feel the spring exerting a force upward on their hand. Clement (1987b) found that almost all students understand the anchoring example that a spring can push back on their hand, but many were still unconvinced that this is a valid analogy to the target example which is the book on the table. This is because the anchoring example is too far removed from the target example and so intermediate examples which serve as bridges must be given. These might be the book on the spring, then the book resting on a piece of foam, and then the book resting on a flexible board. In this progression, students gradually move away from the anchor and towards the target.

Although there is enough evidence that misconceptions among students lead to poor understanding of a text, a student with misconceptions sometimes acquires new knowledge at the same speed and with the same types of processes as does a student without misconceptions (Kendeou & van den Broek, 2005). Research in science education shows consistently that students with misconceptions are relatively unaware of conflicts between their knowledge and the information (Guzzetti, Snyder, Glass, & Gamas, 1993). When the teacher asks students with misconceptions to elaborate a concept, they integrate their background knowledge as do students without misconceptions (Hannon & Daneman, 2001). But the content of knowledge-based answers in the domain reflects the misconceptions and students are only able to give fewer valid explanations. Such a lack of explanations can undermine students' success in other tasks such as problem-solving in science or understanding expository texts (Ohlsson, 2002). Stavy and Tirosh (1996; 2000) examined common thinking patterns of students having misconceptions in different areas. They found that by creating logical environmental relations, students try to understand the given situation to a certain extend without having a real understanding of the concept. A question arises here: How do different students understand knowledge and knowing? The nature of students' understanding is best expressed in the following quotation:

> Epistemology is always *personal*. The point of the probe is always in the heart of the explorer: What is *my* answer to the question of the nature of knowing? I surrender to the belief that my knowing is a small part of a wider integrated knowing that knits the entire biosphere or creation. (Bateson, 1980, p. 93)

Research on students' personal epistemologies (Hofer & Pintrich, 2002) has conceptualized misconceptions as stable beliefs or stages of development. Hammer and Elby (2002) proposed that personal epistemologies are comprised of manifold epistemological resources. Some students believe that (1) understanding physics means learning formulas and facts; (2) knowledge of physics is loosely related with what happens in the real world; and (3) learning physics means memorizing content of the physics textbook. In contrast, other students may believe that (1) understanding physics means developing sense of basic principles underlying it; (2) the principles of physics explain the phenomena of physical world; and (3) the process of learning physics leads to modifying one's own understanding.

Although students activate and use their prior knowledge during the learning process, however, due to the misconceptions they fail to incorporate new information into their prior knowledge. Research on students' misconceptions also shows that they are resistant to change (Hameed, Hackling, & Garnett, 1993; Baser & Geban, 2007) that also affects students' comprehension of new knowledge (Kendeou & van den Broek, 2005; Diakidoy & Kendeou, 2001). This results in the compartmentalization of knowledge. Such compartmentalization is a crucial educational problem. How does a teacher nurture incorporation rather than compartmentalization? An important prerequisite would be that the teacher is aware of inconsistencies between students' prior knowledge and new information they are learning (Kendeou & van den Broek, 2005). Understanding misconceptions and the effect of specific aids on students' knowledge structures is very important. Therefore, teachers must address misconceptions if they want to alter them. There has been considerable interest in attempts to design instructions to facilitate cognitive structure change, and to address misconceptions (Ausubel, 1963, 1968; Novak, 1985; Treagust & Duit, 2008). Information about students' misconceptions in a class can assist the teacher in preparing effective lesson plans (Atkinson, 2004, p. 379). This study may benefit teachers' understanding of students' knowledge structures and thinking, which may lead to using improved pedagogy and instructional strategies.

STRUCTURAL ASSESSMENT OF KNOWLEDGE

Structural assessment of knowledge refers to a procedure for evaluating an individual's knowledge within a particular domain. Structural assessment of knowledge is based on the premise that conceptual knowledge involves not only knowing facts, procedures, and concepts, but also having an understanding of the *interrelationships* among those facts, procedures and concepts (Goldsmith & Johnson, 1990). It reflects a learner's understanding of why a procedure or a concept works (Engelbrecht, Harding, & Potgieter, 2005) or of whether a procedure is legitimate (Rittle-Johnson, Siegler, & Alibali, 2001). As a learner becomes more knowledgeable in a domain, he/she begins to organize knowledge by constructing meaningful relationships among facts, procedures and concepts rather than accumulating declarative and/or procedural knowledge. This organization or interrelatedness of concepts or facts in memory is called *schema* (Eggen & Kauchak, 2007). Learning and attaining new knowledge is mainly dependent on how we organize the knowledge in our memory (Jonassen, Beissner, & Yacci, 1993). An expert's knowledge is organized and stored in the form of schemas whereas novice knowledge is not (*e.g.,* Engelbrecht *et al.,* 2005; Gresham, 2007).

Therefore, schema theory, which explains the nature of memory, how it is structured, variables that affect its structure and consequently, how this interwoven structure affects our retrieval capabilities, provides the theoretical basis for understanding the conceptual knowledge of a novice or an expert. How experts organize and interpret information and how they use this information to solve problems depend on their knowledge acquisition. Review of the literature on the differences between experts and novices and characteristics of expert instructors validate the importance of a highly organized schema in acquiring knowledge.

METHODS FOR IDENTIFICATION OF MISCONCEPTIONS

There are several methods that can be used to identify misconceptions among students. These include (1) Teachers' interviews, (2) Students' interviews, (3) Students' tests. Each of these methods has weaknesses and strengths with regard to the type of information they produce, time and effort required to implement them and their ability to cover a certain population.

Teachers' interviews were employed in the domain of physics (Pine, Messee, & St. John, 2001) and statistics (Khazanov, 2006) to develop a list of common misconceptions among students. The strength of this qualitative approach is that experienced teachers have taught many students and they have a great deal of information about their students. The main weakness of this approach is that data can be collected only from a bunch of experienced teachers, so there is always a risk of not getting authentic information if an experienced teacher misinterprets students' difficulties or lacks interest in reporting students' misconceptions. Another risk in this approach is that it does not get information directly from students.

Some researchers like Hamza and Wickman (2008) interviewed eight pairs of students during a practicum on electrochemistry. This research provides an analysis of how scientific misconceptions influence the development of students' reasoning as compared to other students during the learning experiences. Shaffer and McBeath (2005) used a questionnaire and showed that students have striking misconceptions about what the motion of projectiles should look like from various perspectives. These types of approaches require a lot of time to collect data and are difficult to generalize, although researchers can collect in-depth data directly from students.

The combination of students' interviews and open-ended questionnaires was used by Guisasola, Almudi, and Zubimendi (2004) to identify misconceptions among students regarding magnetic field theory. Acar and Tarhan (2007) used open-ended questions and also interviewed some students to collect information about misconceptions among students in the field of electrochemistry. Using constructivism, Acar and Tarhan tried to explain "why students bring misconceptions to chemistry classes and where these misconceptions come from" (p. 351). To change these misconceptions, Hodson and Hodson (1998) summarize the four main steps of a constructivist approach as:

1. identifying students' views and ideas;
2. creating opportunities for students to explore their ideas;
3. providing stimuli for students to develop, modify and where necessary, change their ideas and views; and
4. supporting their attempts to re-think and reconstruct their ideas and views.

An instructor needs to understand the misconceptions a student has in a domain to comprehend what the student expects from the instructor. Once the misconceptions of the students are understood and uncovered, they can be documented for future references. Finally, after individualized feedback, the knowledge structure of a student is re-evaluated to see if they correctly change their conceptions (verification). However, it is very difficult for an individual instructor to manage such research in which he or she has to use open-ended questions during interview with every student in a class.

Multiple-choice test is another way to analyze misconceptions among students. Baser and Geban (2007) administered a multiple-choice test of 72 students to understand the misconceptions among students in the domain of heat and temperature. Korner (2005) went a step ahead and analyzed the patterns in the incorrect answers on a multiple-choice test to predict misconceptions among students about hierarchical graphs. Other examples come from Sencar and Eryilamaz (2004) who assessed misconceptions in electric circuits using multiple-choice tests. The multiple-choice tests are well suited to predict misconceptions around specific topic. However, in these types of tests the choices are fixed and the reason behind the wrong answer has to be assumed by the researcher. Furthermore, it is more difficult to predict misconceptions in some domains, like literature or religion, using multiple-choice tests.

Therefore, different methods of identifications of misconceptions have different weaknesses and strengths. The three methods discussed above are largely employed for identifying misconceptions related to a specific topic. On the other hand, this study attempts to visualize conceptions or misconceptions carried by the students through understanding their mental models generated using pathfinder networks.

IDENTIFICATION OF MISCONCEPTIONS USING A CONCEPT MAP

A concept map is a visual representation of how concepts are related to each other. Trochim (2003) who developed methodology for concept mapping describes it as "a structured process, focused on a topic or construct of interest, involving input from one or more participants, that produces an interpretable pictorial view (concept map) of their ideas and concepts and how these are interrelated". According to Novak & Cañas (2008), "Concept maps are tools for organizing and representing knowledge. They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts or propositions, indicated by a connecting line between two concepts". Therefore, each concept is a node, connected to other related concepts by a link line.

Concept mapping can be used as a methodology for organizing different ideas and concepts to evaluate a group of diverse people or a group of stakeholders. Further, it can be used as an integrated mix-method (Greene, Caracelli, & Graham, 1989) because its quantitative and qualitative components are quite interwoven that enable researchers to articulate their research direction and to represent their findings in a variety of quantitative and qualitative ways to give awareness of the issues at hand. Therefore, these concept maps can be used to understand learning process, to make instructional strategy, as an aid for curriculum planning and to diagnose understanding (Novak, 1990a,b; De Simone, 2007). An extensive amount of literature is also available on the use of concept maps as an alternative form of assessment (Ruiz-Promo, Schultz, Li, & Shavelson, 2000; Ruiz-Primo, Shavelson, Li, & Schultz, 2001). For example, concept maps were administered over a particular interval to assess change in knowledge structure of students about electricity (Anderson, Lucas, Ginns, & Dierking, 2000), high school science (Kinchin, Hay, & Adams, 2000), and university students (Walker & King, 2002).

There are several methods to score concept maps which include holistic scoring (based on overall understanding of the concepts represented by the map), density scoring (based on the number of nodes and links), and validity scoring (based on correct links). These concept maps are predictive with or without comparison to a master map (McClure, Sonek, & Suen, 1999). There are strengths and weaknesses of each type of concept map (Ruiz-Primo & Shavelson, 1996). Visual examination through concept maps limits the number of students who can validly be studied. Most of these scoring methods predict an overall score, but do not indicate the area of particular misconceptions. This is useful for the summative assessment purpose, but do not give enough information to design an improvement strategy or to give individualized feedback to a student. One of the greatest concerns is that the quality of concept maps is dependent not only on students' domain knowledge but also on their skill with technique. Students often require a great amount of instruction and support to learn concept mapping (Williams, 2004).

IDENTIFICATION OF MISCONCEPTIONS USING PATHFINDER NETWORKS

One comprehensive technique to generate mental models of the participants that does not require extensive instructions and allows for both location of specific misconceptions and the investigation of a large number of students is pathfinder networks (abbreviated *PFnets*; Schvaneveldt, 1990). Pathfinder is a computer-based network scaling technique which offers a quantitative method for representing and evaluating structural knowledge (Azzarello, 2007). Structural knowledge reflects how knowledge is organized or how concepts within a domain are interrelated. The pathfinder network scaling algorithm generates networks from proximities. These proximities can be obtained from similarities, correlations, distances, conditional probabilities, or any other measure of the relationships among entities. The entities are often concepts of some sort, but they can be anything with a pattern of relationships. In the pathfinder network, the entities correspond to the nodes of the generated network, and the links in the network are determined by the patterns of proximities. The process of generating a pathfinder network involves explicit steps for:

1. knowledge elicitation;
2. knowledge representation; and
3. knowledge assessment.

In the knowledge elicitation phase, an individual judges the relatedness of pairs of concepts from a certain domain on a rating scale. In the knowledge representation phase, these relatedness ratings are transformed to structural representation of the individual's knowledge by using the pathfinder scaling algorithm. This structural representation is referred to as a pathfinder network. In the knowledge assessment phase, the individual's pathfinder network is evaluated by comparing it to a domain expert's pathfinder network derived in the same manner. This may enable a researcher to evaluate both the understanding and misconceptions an individual has in a particular domain.

Pathfinder networks can be generated for an individual student or for a group of students. This may enable a teacher to understand learning process of an entire group of students or on an individual basis. Comparison of networks could also be made between groups or between individuals (whatever is deemed appropriate). The scaling algorithm reveals information about structural knowledge of a participant that cannot be seen from the initial raw data.

CHAPTER 2: LITERATURE REVIEW

Conceptual knowledge and cognitive skills of an individual develop through distinct stages, progressing from *declarative knowledge* to *procedural knowledge* (Anderson & Schunn, 2000). The declarative stage of learning reflects the amount of knowledge or facts learned by an individual. Ryle (1949) calls this type of knowledge as *knowing that.* Although individuals in the declarative stage can define or describe the objects of knowing, they are often slow and cannot necessarily use that knowledge accurately. In the procedural stage, individuals are able to activate background knowledge and develop understanding. Ryle calls this type of knowledge as *knowing how.* Solving problems and writing an essay are some of the examples of procedural knowledge. Declarative knowledge and procedural knowledge are encoded in long-term memory in complex interrelationships called *schemas* (Eggen & Kauchak, 2007). An expert's schema in a domain is comprised of both declarative and procedural knowledge, as well as the appropriate links amongst different bits of declarative and procedural knowledge. Such a schema production is an effective instructional strategy for helping students to acquire integrated declarative and procedural knowledge. However, a third type of knowledge is known as *structural knowledge.* Structural knowledge is an intermediate type of knowledge that reflects the organization and interrelationship of concepts within a domain (Diekhoff, 1983; Jonassen *et al.,* 1993). Therefore, it is also known as *internal connectedness, integrative understanding* or *conceptual knowledge* (Jonassen *et al.,* 1993). It has also been referred to as *cognitive structure*, the pattern of relationships among concepts in memory (Preece, 1976). Structural knowledge mediates the translation of declarative knowledge into procedural knowledge and facilitates its application. This interrelatedness of knowledge becomes evident in thinking and practices of an expert.

Structural knowledge is the knowledge of how declarative and procedural knowledge become interrelated within a domain through training and experience. Therefore, structural knowledge is perhaps a more important part of cognitive processing—affecting learners' ability to retrieve and use information (Meyer & Sugiyama, 2007; Jee & Wiley 2007; Mahon & Caramazza, 2007). This suggests an examination of structural knowledge as a good predictor for developing authentic evaluation strategies for student's performance.

The basic assessment procedure for declarative knowledge is straight forward. On each assessment occasion, teacher gives the students a test asking factual questions. The results provide him/her with the picture of students' current knowledge in a particular domain. The assessment of classroom knowledge in these types of conventional tests is usually evaluated in terms of the percentage of correct answers by students or their ranking in the classroom population. In some cases students' performance may be analyzed into subscale, but mostly classroom learning is represented in terms of unidimensional scale, reflecting the student's relative standing in his or her class. Many researchers (*e.g.* Goldsmith & Johnson, 1990) criticize this conventional approach of assessing classroom knowledge. They argue that the percentage of correct answers may be appropriate for certain types of knowledge (*e.g.,* a student's knowledge of the names of Canadian provinces and territories) where the conceptual relationship among the knowledge elements is not relevant. In such cases, it is reasonable to assume that the "facts" comprising the domain are independent and additive (Goldsmith & Johnson, 1990, p. 241). But the domains of conceptual knowledge involve the relationship or the organization of elements within a certain domain. This domain of knowledge is not assessed and represented in classroom testing. A traditional testing system may be very convenient in assigning grades to students, but it tells us very little about what a learner knows or does not know. The fundamental problem with conventional educational assessment procedures is that they are, in principle, incapable of explicitly representing the abstract nature of conceptual domains (Goldsmith & Johnson, 1990, p. 241).

Concept mapping is a structural and conceptual process that has evolved in many different disciplines (Bonham, 1993). As a systematic, methodological process, concept mapping can be a useful tool for developing and directing evaluation theory and practice (Trochim, 1989a). For example, conceptual frameworks in a specific domain of knowledge can be developed through the concept mapping process (Cropper, Eden, & Ackerman, 1990; Novak, 1990a,b). Relationships among these concepts can be displayed. The resulting map can be compared to an expert/instructor's map and the similarity between them is calculated on the basis of common links. *Pathfinder networks* were the result of such an effort to develop network models to represent knowledge from proximity data during the year 1981 (Schvaneveldt & Durso, 1981). Popular scaling techniques that existed at that time were multidimensional scaling (MDS) and cluster analysis. MDS or cluster analysis creates a visual representation of the structural framework underlying the set of concepts (Fenker, 1975). MDS is limited to symmetrical data, or concepts that are linearly related, and cluster analysis is limited to class-inclusion structures, or concepts that are related by position. Pathfinder scaling techniques were developed to eliminate the limitations of other scaling techniques (Dearholt & Schvaneveldt, 1990). Proximity matrices in pathfinder scaling algorithm may be symmetrical or asymmetrical unlike MDS (Jonassen, Beissner, & Yacci, 1993). Consequently, pathfinder networks are either in the form of a directed graph (symmetrical similarities or distances) or an undirected graph (asymmetrical).

Characteristics of a pathfinder network (or *PFnet*) are determined by the two parameters, r and q and the networks thus generated are denoted as *PFnet* (r, q). The r parameter defines the Minkowski metric, and determines how the distance between two nodes which are not directly

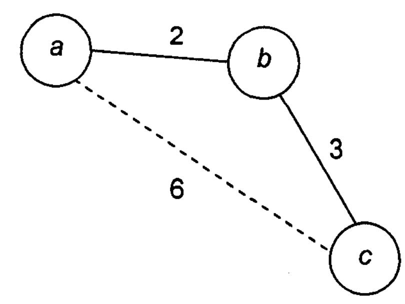


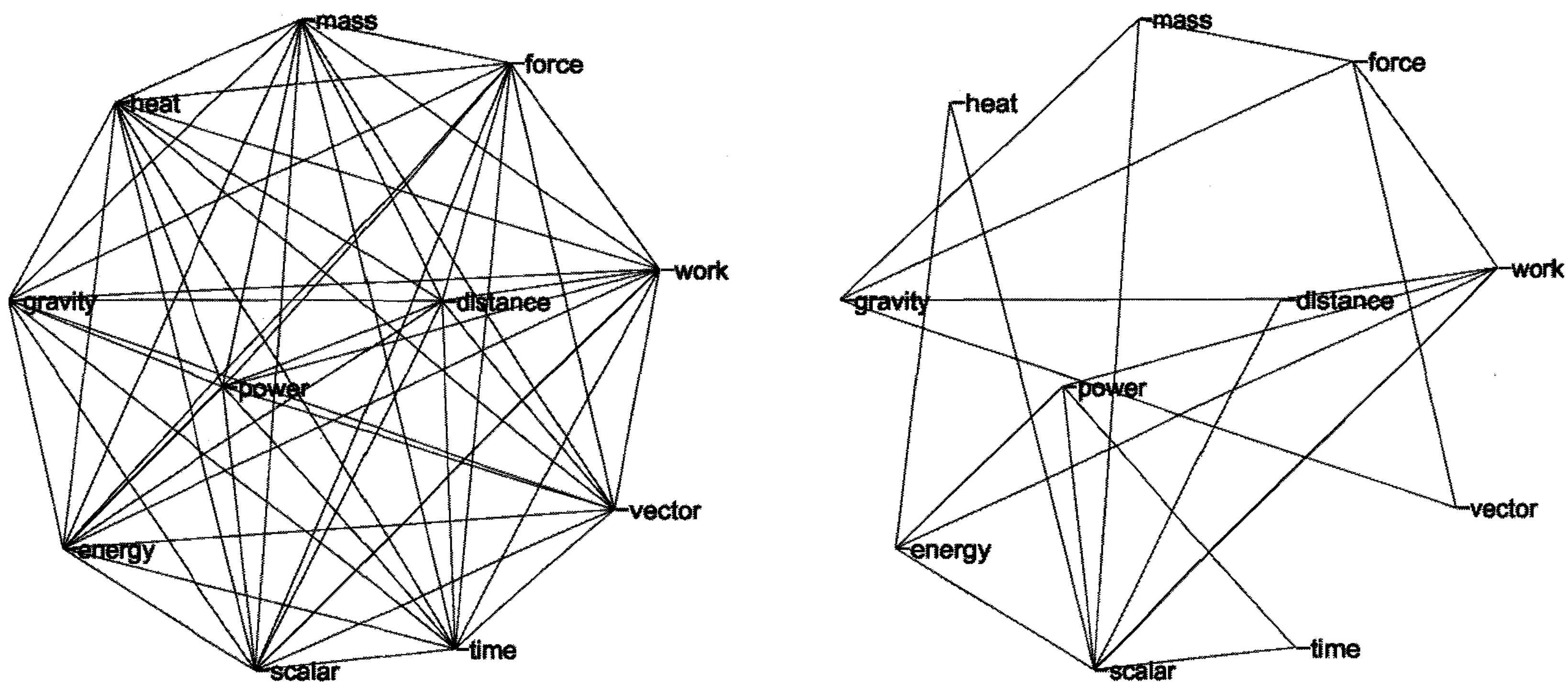
Figure 2.1: Generalized Triangle Inequality: The dotted line connecting nodes *a* and *c* violates triangle inequality

linked is computed (semantic distance between each pair of concepts). The *q* parameter is a limit on the number of links in the paths examined in constructing a network. Its value determines the maximum number of links in paths in which the *triangle inequalities* are guaranteed to be satisfied in the resulting network. The triangle inequality eliminates redundant or counter-intuitive links in a pathfinder network. The triangle inequality specifies that the sum of the distances of two sides of a triangle must be greater than or equal to the third side. Using the distance notation, say $d(a, b)$, to indicate the distance from point a to b, the triangle inequality requires that a third point, say c, be restricted as follows:

$$d(a, c) \leq d(a, b) + d(b, c)$$

As an example in Figure 2.1, the length of the path between concepts *a* and *c* is 6, but the sum of the paths between *a-b* and *b-c* is only 5, therefore the direct *a-c* link will be removed (Acton, Johnson, & Goldsmith, 1994, p. 305). Although some of the previous studies examined metrics to allow for the violation of the triangle inequality, *e.g.,* Hutchinson's Netscale procedure (Hutchinson, 1989), Schvaneveldt criticizes this early work as inadequate, since it only considers two of the links (sides of a triangle) in determining the validity of a third link (Schvaneveldt, 1990). *PFnets* allow for an extension of the triangle inequality by examining paths with a number of links, from a minimum of two (the traditional triangle inequality) to a maximum of $n - 1$, where n is the total number of nodes (concepts) in a network. The changes of these two parameters can impact the *PFnet* complexity. The complexity of the network decreases as either or both of these two parameters increase, *i.e.,* when the parameter r and q have their maximum values ∞ and $n - 1$ respectively, the *PFnet* is the simplest network, thus making interpretation of knowledge structure easier. However, an increase of q would result in an increase of computational complexity. Figure 2.2(*a*) shows a fully connected graph and Figure 2.2(*b*) shows how the pathfinder algorithm scales raw data from a fully connected graph to a pathfinder network that reveals only the most salient links among the selected concepts by setting r and q equal to ∞ and $n - 1$ respectively.

The software *Knowledge Network and Orientation Tool* (*KNOT*) used to generate *PFnets* also provides several useful functions for objective evaluation of *PFnets* such as "similarity" and "coherence". *Similarity* analysis between two or more networks generates a *similarity index* to compare individual *PFnets,* on the basis of how many total numbers of links the *PFnets* have in common (Goldsmith & Davenport, 1990). This function actually measures the similarity between mental models and is the main method for assessing *PFnets* (Schvaneveldt, 1990). The similarity index examines the degree to which the same concept (represented by a node in a network) in several *PFnets* is surrounded by similar neighbouring concepts. Pathfinder compares each concept in two networks and then averages the results across the nodes to compute an overall similarity index. Similarity index is the number of links in common divided by the number of links that are in either network (similarity index = common links / (total links − common links)). Result ranges from 1 to 0 and so the similarity index takes three general forms: no, moderate, and strong similarity. If the similarity index is below 0.4, it indicates little or no similarity. If the similarity index is from 0.4 through 0.7, it suggests that there is a moderate degree of similarity. If the similarity index is more than 0.7, it suggests that there is very good to strong similarity between the two networks. These cut-off values are arbitrary and depend on the context. For example, 0.7 might not be considered strong similarity if comparing two experts, but would be if comparing a novice to an expert.



(a) Fully connected *PFnet* with eleven concepts

(b) The *PFnet* ($r = \infty$, $q = n-1$) has the same 11 nodes but only 20 links revealing the conceptual structure

Figure 2.2: Two Pathfinder networks

This similarity function is useful for comparing students' *PFnets* with an instructor's *PFnet* or for comparing *PFnets* generated by the same individual before and after specific instructions. On the other hand, KNOT's *coherence* function generates a measure of internal consistency, which is a predictive of the degree of domain expertise (Johnson, Goldsmith, & Teague, 1995). Coherence is a within-subject correlation of relatedness ratings that is based on the assumption that concepts related to each other should also be related to other concepts, they have in common (Kokoski & Housner, 1994). Thus a more consistent set of ratings will produce a higher coherence.

A considerable amount of literature on pathfinder networks is available. This literature is crucial in providing the basis for an evaluation of pathfinder networks. Underlying disciplinary foundations are critical for establishing the connections to present pathfinder networking process. Exploration and understanding of these principles help to situate the context in which the pathfinder network is used. Since its inception, pathfinder networks are used in the structural assessment of knowledge in diverse domains, including: schema (Schvaneveldt, 1990) and problem solving schema (Dayton, Durso, & Shepard, 1990), author cocitation analysis (Whit, 2003), flight training (Schvaneveldt, Beringer, & Lamonica, 2001), and software requirement understanding (Kudikyala & Vaughn, 2005). Pathfinder networks have also been used in the field of Human Computer Interaction (HCI). Some prominent examples of HCI usage include information visualization on the world wide web (Chen, 1997; Chen, Gagaudakis, Rosin, 2000a), content-based image visualization (Chen, Gagaudakis, Rosin, 2000b), image database visualization (Gagaudakis, Rosin, & Chen, 2000), the design of a document retrieval interface (Fowler & Dearholt, 1990; White, Buzydlowski, & Lin, 2000) and designing interfaces for on-line help for UNIX operating system commands (McDonald, Paap, & McDonald, 1990).

Schvaneveldt, Dearholt and Durso (1988) investigated applications of pathfinder for problems in cognitive modelling, knowledge representation, knowledge elicitation, and user-computer interface design. They have been used to model the knowledge structure of experts and novices in many domains like computer programming (Cooke & Schvaneveldt, 1988; Trumpower & Goldsmith, 2004), conceptions about computer networking (DiCerbo, 2007), nursing education in community health (Azzarello, 2007), mental health (Ober & Shenaut, 1999), pulmonary physiology (McGaghie, Boerger, McCrimmon, & Ravitch, 1996), physical education teaching methodology courses (Housner, Gomez, & Griffey, 1993), psychological research techniques (Goldsmith & Johnson, 1990) and physiological responses (Michael, 1998). Moreover, pathfinder networks have been used to analyze the perceptual differences between waste management experts and general public regarding terms used to describe nuclear waste (Martin, Stephan, & Holloway, 1993). Chen (1999) used pathfinder networks technique to study cited-author data. The output consists of a network with the names as nodes and the most salient linkages between names as links.

In a study of statistics problem solving, Trumpower, Guynn, and Goldsmith (2004) found that different types of practice problems led to the acquisition of a specifically hypothesized subset of links in the participants' *PFnets*. Subsequent problem solving performance was related to the presence of those critical links. In one of his recent studies, Trumpower (2008) demonstrated how the structural assessment of knowledge procedure may be extended to diagnostic assessment. Previously, structural assessment of knowledge was primarily used as a global measure of conceptual knowledge. But, in his recent study he showed that the absence of *specific* links in *PFnets* can be used to diagnose misconceptions that lead to errors on *specific* types of problems. He identified two subsets of links (*i.e.,* schemas) and used them to successfully predict performance on two different types of programming problems. Participants who failed to possess the Pointer schema performed more poorly on Pointer-type problems, but not on other types of problems, than those who possessed the Pointer schema. Likewise, participants who failed to possess the Go-To schema performed more poorly on Go-To-type problems, but not on other types of problems, than those who possessed the Go-To schema. Trumpower (2008) further asserts that in order to efficiently and effectively improve students' domain knowledge, instructions must be able to target these specific missing links and misunderstandings.

Conceptually, pathfinder network methodology is rooted in the semantic network to define knowledge representation (Meyer & Schvaneveldt, 1976). Therefore, it is widely used to produce the knowledge structures of experts and students using a common set of concepts. Then the knowledge structures of students are compared to that of an expert (generally instructor) for misconceptions (Goldsmith & Johnson, 1990; Azzarello, 2007). The expert referent network is usually created from course instructor's relatedness ratings. Research shows that a referent network based on the averaged ratings of several experts is usually a better referent network for students' assessment than a single expert's ratings because it transcends the various idiosyncrasies of individual experts (Goldsmith & Johnson, 1990; Taricani & Clariana, 2006). The referent network created from the statistically averaged ratings of several experts also yield higher correlations with skill-based performance than do network created from ratings obtained through a single expert (Day, Arthur, & Gettman, 2001). The main advantage of using averaged ratings is that personal biases can be overcome through aggregation. The idea of an idealized referent network does not in any way constrain individual creativity. The fact is, although expert networks are more similar to one another than students structures, each expert's organization has unique characteristics.

VALIDITY OF PATHFINDER NETWORKS

Evidence for the validity of pathfinder algorithm as a measure of structural knowledge is based on the assumption that there is some ideal knowledge organization that best reflects the structure of the domain and that cognitive structures become more like this ideal structure as experience in the domain increases (Acton, Johnson, & Goldsmith, 1994). Two frequently used approaches to address validity are demonstrations of increase in the similarity of a pathfinder network to a referent network after instructions, and demonstrations that the similarity between students' and expert's pathfinder networks is positively related to other measures of classroom achievements, such as course grades (Gomez, Hadfield, & Housner, 1996), or examination scores (Azzarello, 2007; d'Appolonia, Charles, & Boyd, 2004; Goldsmith, Johnson, & Acton, 1991).

Several studies have shown that there is a positive change in students' *PFnets* before and after instructions. For example, research demonstrated that students' *PFnets* become increasingly similar to instructor's *PFnet* from pre- to post-intervention in the field of pulmonary physiology (McGaghie *at el.,* 1996; McGaghie, McCrimmon, Mitchell, Thompson, & Ravitch, 2000). In another study, Azzarello (2007) investigated 102 students of health nursing during an 8-week course focusing on concepts, related to nursing and public health strategies for populations, by using pathfinder techniques. He reported that the mean similarity of the students' *PFnets* to the referent network increased significantly from 0.19 before the course to 0.24 after the course completion. The students' pre-course *PFnets* had a mean coherence of 0.32 and their post-course *PFnets* had a mean coherence of 0.38, a significant increase from the beginning to the end of the course. Findings were similar in studies of computer programming concepts (Trumpower, 2004) and computer networking (Dicerbo, 2007).

Several studies also have shown a positive relationship between the similarity of students' and instructor's networks and students' test scores. Goldsmith, Johnson, and Acton (1991) used the pathfinder networks algorithm and found that the similarity between each student's *PFnet* and the instructor's *PFnet* was highly predictive of the examination scores over the course of the semester. In another study, Azzarello (2007) found that a student with the structural knowledge that was coherent and similar to the instructor's performed better in the class. The students' structural knowledge also differentiated between high-performing and low-performing students. For example, in a study of 53 undergraduate students enrolled in a teaching methodology course, researchers examined the similarity between students' and instructor's *PFnets* created from ratings among 27 domain concepts. The correlation between the similarity of students' and instructor's *PFnets* and test averages was significant ($r = 0.52, p < 0.001$) (Gomez *et al.,* 1996). The study conducted by Azzarello (2007) examined the similarity and correlation between *PFnets* for 102 community health nursing students and an instructor's network for a course. There was no significant correlation between the mean examination scores and pre-course coherence ($r = 0.07, p = 0.238$) or pre-course similarity ($r = 0.16, p = 0.057$). The mean examination score was positively correlated with post-course coherence ($r = 0.27, p = 0.003$) and post-course similarity ($r = 0.29, p = 0.002$).

The stability of experts' pathfinder networks may vary depending on the context of the data collection task (Gammack, 1990). The meaning of a concept depends to some degree on the particular context of use, and this relationship may vary across contexts, and relationships strong in one set of circumstances may not apply in another. For example, a liger is considerably more central if related to a zoo while less central if related to jungle animals. In a series of studies examining the stability of experts' *PFnets* of train locomotives, Gammack (1990, p. 226) argues, "across different elicitation conditions, no unique conceptual structure emerged when it might have been expected. Methodological and psychological reasons were considered as explanation for this instability, and with hindsight, it seems sensible to expect structural variation for a variety of reasons". The actual circumstances and any pre-existing schemas may emerge uncompromised, which influence and may modify the applicability of a given relationship. The instability of knowledge representation is neither caused by, nor unique to pathfinder, which provides a tool for investigating the sources of instability in conceptual representation, such as individual theories and biases. Gammack further argues that despite of some variations, the pathfinder is particularly useful in contexts where experts' domain conceptions are concise and remain relatively constant.

GAPS IN THE RESEARCH

Although pathfinder networks have proved their utility in a variety of applications over the last two decades, there is no evidence of investigating a particular node or a particular concept in the network. All applications consider these networks as a unit to calculate network similarity of students and their instructor to measure conceptual knowledge. These applications do not use individual node or individual concepts. Although overall measurement of the similarity of students' and their instructor's pathfinder networks is useful for summative assessment, it is less useful for formative assessment. Pathfinder networks have been used in the domain of physics to understand how students and experts organize knowledge about physics. But the individual nodes generated by pathfinder networks have never been used to study misconception or weak conception about a particular concept for formative assessment. That is, network similarity measures only indicate *how much* students' structures differ from instructor's structure; they do not indicate specifically *in which subsection* structures differ. This research, through an experiment, is a step forward to provide evidence that an individual node in pathfinder network can be explored to study misconceptions around a particular concept in the network. This may enable an instructor to give individualized feedback to students to address those misconceptions. Therefore, the research demonstrates the potential utility of pathfinder networks for formative assessment.

CONCEPTUAL FRAMEWORK OF THE STUDY

The primary purpose of pathfinder networks is to represent the knowledge structure of participants. This purpose of pathfinder networks provides the basis of a conceptual framework of this study, as shown in Figure 2.3, to address two practical issues: (1) identifying the misconceptions among high school students around a particular concept, and (2) addressing these misconceptions by giving them individualized instructions and exercises around that particular concept.

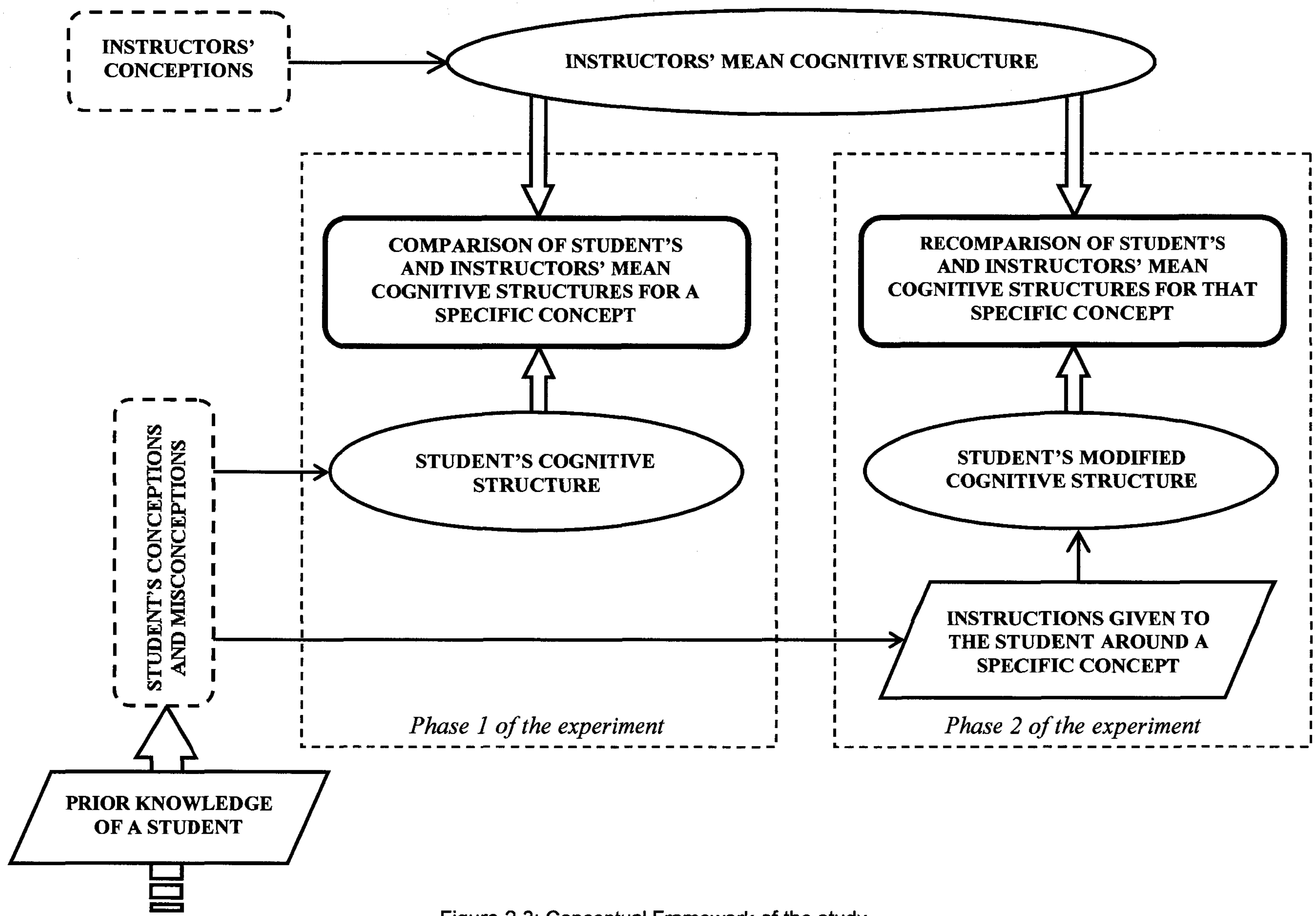


Figure 2.3: Conceptual Framework of the study

RESEARCH QUESTIONS

Research using pathfinder networks continue to proliferate in the measurement of conceptual knowledge within a wide range of disciplines and domains of inquiry. Many researchers claim about applications of pathfinder networks in evaluation practices. Over the past twenty years, research of this category was done in abundance. While variations in approach have provided a wide range of pathfinder networks applications, the use of the pathfinder networks for formative assessment has been not considered. Using the quantitative research approach, pathfinder networks' contribution in formative assessment and practice can be extracted. Knowledge about the potential utility of pathfinder networks for formative assessment will be generated so that teachers and researchers would be able to make an informed decision about such use of pathfinder network.

The study explores the formative assessment capability of pathfinder networks in understanding misconceptions among students as the central research question. Specifically, the study is guided by the following set of questions:

1. What effects do individualized concept-oriented instructions, based on a student's unique knowledge structure, have on the particular concept (or node) in his or her knowledge structure?
2. How do individualized concept-oriented instructions affect other concepts in the student's unique knowledge structure?

My issue and procedural subquestions (Cresswell, 2007, p. 111) are included as Appendix A. Using students' knowledge structures, the study identifies misconceptions about one specific concept. To address those misconceptions, individualized instructions and exercises about that specific concept were prepared for each student. The focus in this context is to identify a node of the pathfinder network that has the most links, and is generated because of the pair-wise comparison of concepts by the instructor. The effectiveness of this method to identify misunderstood and partially-understood concepts and misconceptions is investigated. Therefore, the potential utility of pathfinder networks for formative assessment is explored. This offers the possibility of providing students with extremely comprehensive feedback.

The study tests and validates the same metric at the subset level (for a single node) which is used to compare global similarities/dissimilarities between the pathfinder networks of the students and the instructor. The same metric is used for measuring the understanding and misconceptions at an individual node level and, therefore, this study intends to validate this issue. This study also analyzes the information revealed by a specific concept in the pathfinder networks. As a part of addressing this issue, an analysis to find an effective way to classify the low, moderate, and high similarities in the networks around that specific concept are undertaken. Some researchers (*e.g.* Eryilmaz, 2002) find a gender difference in misconceptions, therefore, data was also analyzed separately for male and female students to analyze differences in their misconceptions.

HYPOTHESIS

The hypothesis of this study is that by conceptualizing the mental models of students by using pathfinder networks, and comparing it with the referent network, it is possible to predict misconceptions among students. Furthermore, the presence of a specific link in the students' *PFnets* would be predictive of their conceptual knowledge about that specific concept. The pathfinder networks thus generated provide insights needed to identify ambiguous, duplicate and misunderstood concepts by the students. These misconceptions can be addressed by giving individualized instructions and exercises to students around that particular concept. I assume that the feedback in terms of misconceptions about a particular concept affects the understanding of that concept among students in terms of increasing the number of relevant links (links around a particular concept which are both in the student's network and the referent network) and decreasing the number of irrelevant links (links around a particular concept which are in the student's network but *not* in the referent network) as compared to the expert's network around that particular concept.

INDIVIDUAL HYPOTHESES

Hypothesis 1

There will be a statistically significant increase in the similarity indices of the pathfinder networks of the students from pre- to post-intervention phase.

Hypothesis 2

In the phase 2 of the experiment, individualized instructions and exercises were given to the students about the concept of *work*. Therefore, it is further hypothesized that there will be a statistically significant increase in the similarity indices of the work concept (a subset of links around the concept of work) in the pathfinder networks of the students from pre- to post-intervention phase.

Hypothesis 3

In the phase 2 of the experiment, individualized instructions and exercises were given to the students *only* about the concept of *work* and not about the concepts of *mass* and *gravity*. Therefore, there will be a statistically non-significant relationship in the similarity indices of mass and gravity concepts in the pathfinder networks of the students from pre- to post-intervention phase.

CHAPTER 3: METHODOLOGY AND DATA COLLECTION

The purpose of this study was to examine the changes in students' pathfinder networks from pre- to post-intervention phase. An attempt was made through those networks to demonstrate the potential utility of pathfinder networks for formative assessment. Therefore, the study used a one-group pre-intervention and post-intervention design. Changes at two levels were examined in students' pathfinder network after giving them concept-oriented individualized instructions and exercises. At the first-level, *PFnets* of each student was considered as a unit. The similarity indices of students' *PFnets* were calculated by comparing these networks with the referent *PFnet* before and after instructions and exercises were given in order to identify the students' understanding and misconceptions. This is primarily a global measure to evaluate conceptual knowledge of the students. At the second-level, *PFnets* of each student was further investigated around a particular concept. For this investigation, the study used a *treatment concept* and a *control concept* design. For *treatment concept*, the concept of "work" was picked for analysis. Concept-oriented individualized instructions and exercises around work were given to the students during intervention phase. The subset of links around the concept of work in the students' *PFnets* was compared to the corresponding subset in the referent network during pre- and post-intervention phases. Two other concepts, the concepts of mass and gravity, were picked for analysis as *control concepts*. The reason for picking these two concepts was that these concepts were least related to the concept of work (treatment concept) in the referent network. No feedback was given to the students around these two concepts. After individualized feedback around the concept of work and no feedback around the concepts of mass and gravity, changes in the students' pathfinder networks from pre- to post-intervention phase were examined to demonstrate the potential utility of pathfinder networks for formative assessment. From this point onward, I will refer to the subset of links around the concept of work as "work concept".

The pathfinder network software applications employed in this study are dependent on the epistemological and methodological orientation. Specifically, the underlying paradigm of the inquiry process guides as to which conceptual framework would be adopted. Like any research in other fields, pathfinder network processes can be situated in a variety of epistemological stances. Traditionally, cognitive psychology relies heavily on scientific inquiry and is approached decidedly through a postpositivistic paradigm. Since quantitative methods are often associated with postpositivist research, pathfinder network methodology fits with the tenets of postpositivism most effectively. Also, the quantitative foundation of pathfinder networks is in the mathematical study of graph theory which is concerned with the general properties of networks (Jonassen *et al.,* 1993). Graph theory is applied to compute similarity in the cognitive structures in the form of pathfinder networks (Schvaneveldt, Dearholt, & Durso, 1988). This suggests that a quantitative approach with postpositivistic paradigm is appropriate for this study.

Ontology refers to the nature of reality (Creswell, 2007, p. 248). In a sense, research on misconceptions among students assumes that students' conceptual models are based on representations of their conceptual knowledge that are filtered and constructed through their perceptions (Parsons & Wand, 1997). I believe that conceptual models using pathfinder networks are based on a cognitive foundation, because pathfinder networks are models of how a student perceives a concept. Furthermore, any social constraint on physics education does not modify the nature of the structural knowledge of physics, but they do have strong implications for the ways teachers see the teaching of the conceptual knowledge of physics. Therefore, pathfinder networks show stability in representation of structural knowledge under different elicitation conditions.

The pathfinder network techniques used in this study investigate the networks of students and the referent network on the assumption that they do not misrepresent the conceptual structure. Information about understanding and misconceptions is assumed largely represented in conceptual structures that are stored in memory and that reflect the actual relations of domain concepts. Since each elicitation task provides a pathfinder network with relationships among the concepts, these networks may be compared. By constructing multiple pathfinder networks of experts, by the same technique addressing the same concepts, it is assumed that spurious relationship due to the experimental error or noise may be removed by averaging. Thus one stable referent pathfinder network displaying a core organization of concepts in a domain could be established.

PARTICIPANTS

Two instructors, with an experience of teaching physics at high school level from 5 to 12 years, identified concepts from the book *McGraw-Hill Ryerson Physics 11* that are essential for understanding the unit on "work, energy, and power". This book is used as a part of Ontario curriculum for University Preparation (SPH3U) at grade 11. Another teacher joined the experts' pool later on, to provide an additional set of relatedness ratings among those concepts, used in the phase 1 of the experiment. All three teachers had diverse teaching experiences. The first teacher was teaching grade 11 at a public high school in Ottawa and his students were recruited as student participants of the study. The second expert had an extensive experience of teaching physics at the Ordinary (O) and the Advanced (A) levels (11 and 13 years of schooling respectively) in the Cambridge school system. The third expert had teaching experiences in the field of physics in different colleges of Pakistan. The latter two experts did not belong to the OCDSB (Ottawa-Carleton District School Board).

The student participants of this research were 24 high school students, taking a credit course in physics at grade 11. The experiment was conducted at one of the top rated high schools of Ottawa as indicated by the ratings done by the Fraser Institute, Vancouver, B.C., in 2007 on the basis of Education Quality and Accountability Office (EQAO) scores and other factors. Permission was taken from the principal of the high school and subsequently from the grade 11 physics instructor to conduct the research in his classroom. The class instructor also agreed to participate in the study by signing his consent form (included as Appendix G). The copies of information letter (included as Appendix D), the consent form for parents (included as Appendix F) and the assent form for students (included as Appendix E) were distributed in the classroom by the physics instructor. The students were asked to sign the assent form and to bring back the consent forms signed by their parents. They were given one week to return these forms to the class instructor. The class instructor handed over these forms to the researcher at the beginning of the first session of the study. Out of the total 28 students in the class, 26 volunteered to participate in the study. Two participants were absent during the second ratings, which reduced the sample size to 24. Out of the total 26 students, 7 were White (Caucasians), 8 were East Asian (China, Korea etc.), 7 were South East Asian (Vietnam, Cambodia, Thailand etc.), 3 were South Asian (India, Pakistan, Bangladesh etc.), and 1 was Arab. There were in total 7 female students and 19 male students. Two male students were absent during the second ratings.

IMPLEMENTATION PROCEDURES

PHASE 1 OF THE EXPERIMENT

The study was conducted during May-June, 2008, which was the last month of the school's session. At this stage it is generally assumed that students have learned most of their syllabus contents. The class teacher told me that the students have recently covered the unit on "work, energy, and power". Therefore, a group of concepts from the unit on "work, energy, and power" was selected from the grade 11 physics textbook (see Appendix H). For this purpose single concepts, and not elaborated concept statements, were chosen. The criteria used for concept selection was (Azzarello, 2007, p. 315):

1. The concept must be covered in the course.
2. The concept must be important for understanding physics domain of "work, energy, and power".
3. The concept must be a representative of "work, energy, and power".

This process of consultation produced a final set of 11 concepts from the unit on "work, energy, and power". The concepts are listed in Table 3.1.

Table 3.1: Main concepts in "work, energy, and power" unit

1. Distance	5. Heat	9. Time
2. Energy	6. Mass	10. Vector
3. Force	7. Power	11. Work
4. Gravity	8. Scalar	

The instrument for data collection was a rating scale from 1 (*completely unrelated*) to 5 (*highly related*). The participants used this numeric rating scale for pair-wise comparison of concepts given to them in the questionnaire (included as Appendix H). Each pair of the concepts was presented in one row and the students and the instructor were asked to rate the strength of relationship between each pair on a scale of 1-5, where 1 indicates little or no relationship between the concepts, and 5 indicates the strongest relationship between the concepts.

1	2	3	4	5
completely unrelated				*highly related*

The pairs were presented to the participants in a random order. All pair-wise combinations of 11 concepts [$(11^2 - 11)/2 = 55$ total pairs, where n is the total number of terms in the list] were created. This list of 55 possible word pairs is included in Appendix H. Goldsmith *et al.* (1991) found that the bigger the questionnaire size, the more stable and accurate the predictions made from a pathfinder network would be (as shown in Figure 5.2). Three pair-wise comparisons were repeated at the end of the questionnaire to check reliability of the reply by the students (Trochim, 1989b). The left-right ordering of the terms of these three pair-wise comparisons was changed during this repeat presentation. Therefore, the total number of word pairs went up to 58. The students and their instructor were asked to think about the physics domain of "work, energy, and power" and to judge the relatedness of each pair of concepts by using a numeric scale from 1 to 5. Many participants were not familiar with this type of assessment technique. Therefore, a simple example of the procedure involving non-study related concepts, and how to score the pair, was given to the participants. For example,

Bird	Blue Jay	rated as a 5
Nest	Mammal	rated as a 1

A complete example is included in Appendix H. Participants indicated their ratings by circling a number that corresponded to their numerical rating for each pair of the concept. It was emphasized upon the participants that the whole range of rating values should be used while completing the ratings. The participants completed and returned the survey after about 15-20 minutes (pre-intervention ratings).

Many researchers argue that even experts in a domain may hold inaccurate ideas or misconceptions about concepts (Borges, Horizonte, & Gilbert, 1999; Stocklmayer & Treagust, 1996). Although misconceptions by experts may be quite different from those by novices, the underlying problems posed by the misunderstandings are similar (Perkins & Simmons, 1988). Therefore, two more expert ratings were taken using the same questionnaire and the same rating scale (1 to 5). The similarity indices of the three experts' ratings were also checked before averaging to make sure that none was an outlier. The average similarity index of the three experts was 0.83, which according to the criteria set for this study was very strong similarity between the networks. The average of three expert ratings was calculated and this averaged ratings provided by three instructors was used to create the referent network.

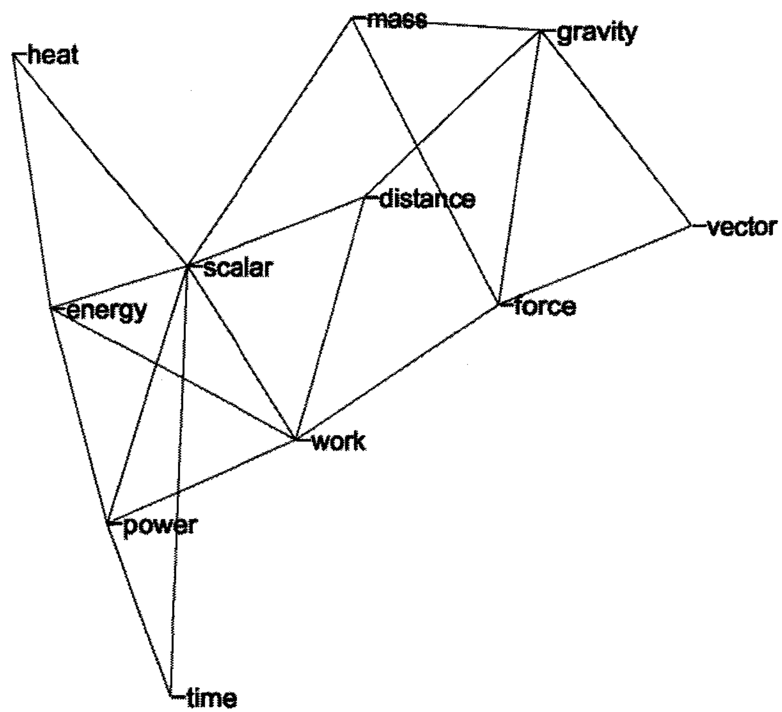
PHASE 2 OF THE EXPERIMENT

As the first step in data analysis, the referent network was generated from the averaged ratings of the experts. This referent network is shown in Figure 3.1(*a*). After analyzing the referent network, the concept of "work" was picked as a central concept because this concept was linked to most of the concepts (5 concepts here) in the referent network. During the second session, students were given the referent network and their own pathfinder network. The students were asked to see the referent network and to add the missing links to their networks (with a dotted line) that the referent network had but they did not, and to delete the additional but irrelevant links from their networks (by crossing them out with an "X") that they had but the referent network did not. They were also asked to try and determine how those linked concepts were relevant (or why the unlinked concepts were irrelevant).

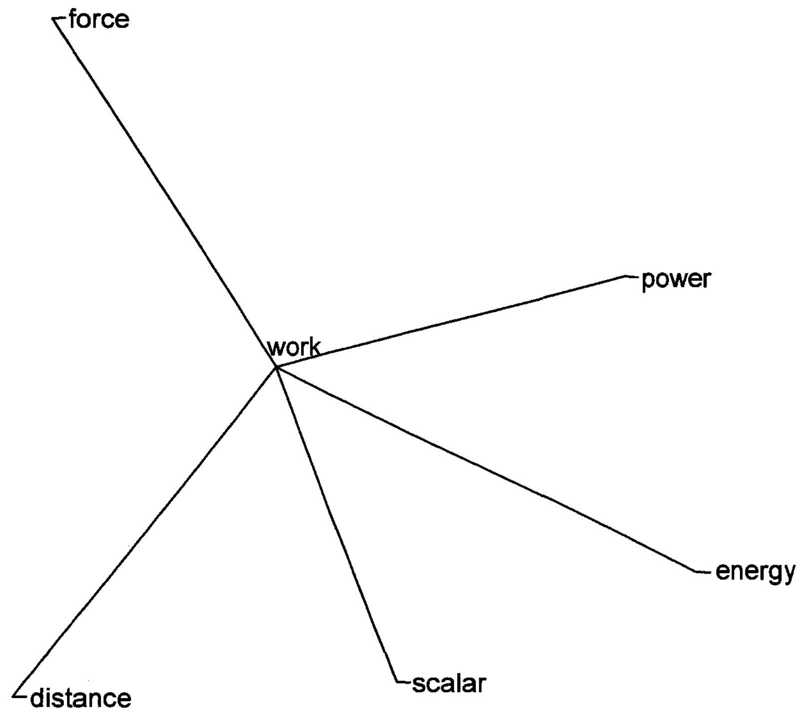
The individualized instructions and exercises to relinquish misconceptions about work concept were prepared for each student and were also given during the second session. The students took about half an hour to complete these exercises during school hours. The physics instructor was present in the class during that time to answer any question about the exercises. The intention was to encourage the students to become independent thinkers and to give an idea of the relationships between work concept and other concepts in the network.

One of the main goals of individualized instructions was to provide knowledge, both procedural (*i.e.,* knowing how) through instructions and declarative (*i.e.,* knowing that) through carefully designed numerical problems which were intended to provide stimuli for students to develop, modify and, where necessary, change their ideas and views, and adaptive strategies that enable the students to apply the knowledge in other contexts (Bransford, Brown, & Cocking, 2000). Under the physics instructor's supervision, students were asked to learn the definitions, to solve some numerical problems, and to read literature about the missing links related to work concept. For example, as shown in Figure 3.1(*b*), work concept in the referent network shows that the concept of *work* is related to five other concepts, *i.e.,* power, energy scalar, distance, and force. Let us consider the work concept in the *PFnet* of the student-25, as shown in Figure 3.2(*b*). The student-25 links the concept of work with only energy and scalar and misses the links of work concept with power, distance and force as compared to work concept in the referent network. This student was first given the following instruction:

> "Your ratings indicate that you see the concept of *work* as being relatively strongly related to the concepts of *energy* and *scalar*. Many expert scientists think that the concept of *work* is also strongly related to the concepts of *power, distance* and *force*. Can you think of ways in which *work* is strongly related to *power, distance* and *force*?"

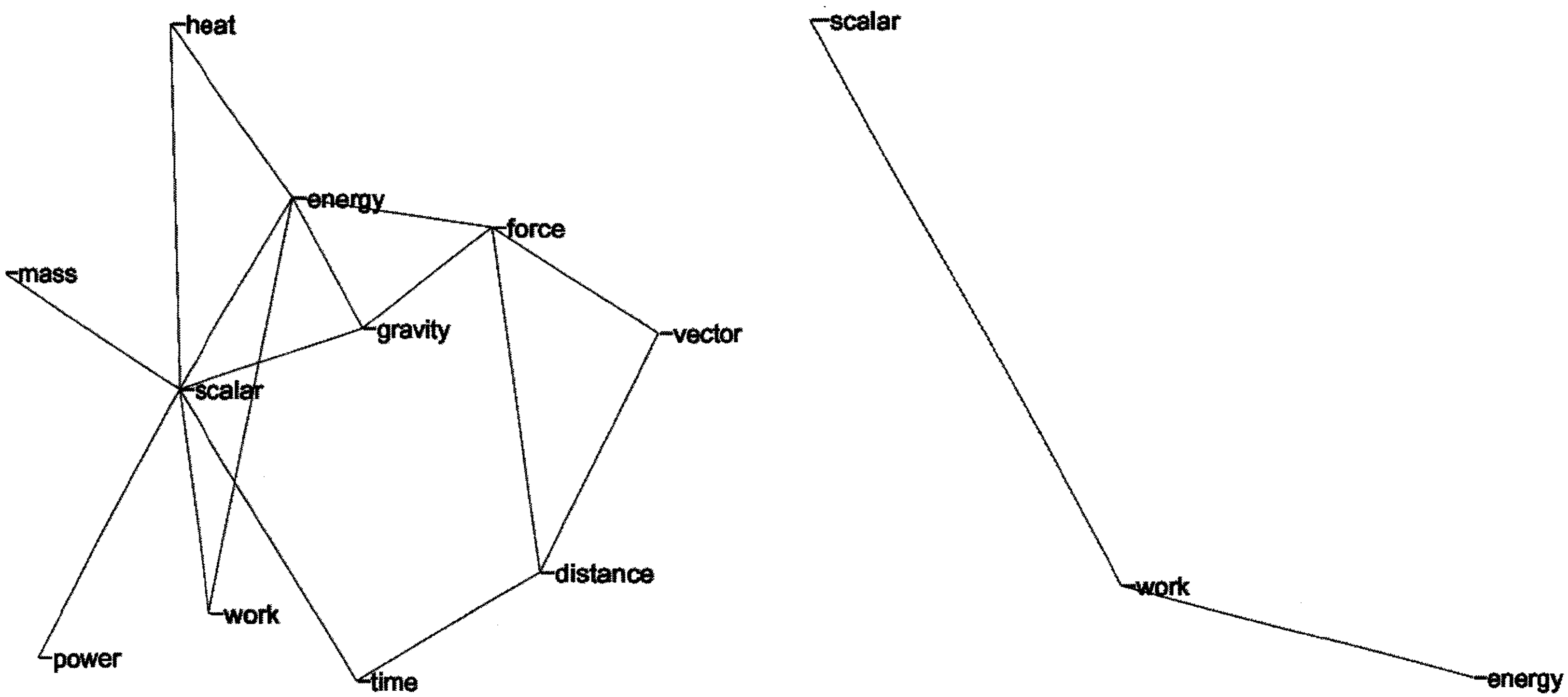


(*a*) The Referent *PFnet*



(*b*) Work concept in the referent network

Figure 3.1



(*a*) Student-25's *PFnet*

(*b*) Work concept in student-25's *PFnet*

Figure 3.2

The subsequent instructions were designed to provide considerable opportunities for the students to argue their own interpretations of both specific concept (work here) and its relationship with other concepts. It began with the following questions for this student to develop more knowledge around his missing links:

To develop more knowledge concerning work-power missing link

1. A mass of 4 kg is raised vertically a *distance* of 2 m in 5 s. Calculate (a) the *work* done in raising the mass, (b) the average *power* required.
2. *Power* can be defined as
   (a) force × distance.
   (b) energy × time.
   (c) work × acceleration.
   (d) the rate of energy transfer.
3. The rate at which *work* is done is called:
   (a) power
   (b) work
   (c) energy
4. If 100 Joules of *work* was done in 10 seconds, what *power* was used?
   (a) 1 kilo Watt
   (b) 10 Watts
   (c) 100 Watts

To develop more knowledge concerning work-distance missing link

1. Which of the following quantities is calculated by multiplying force by distance?

(a) Acceleration

(b) Power

(c) Pressure

(d) Work

2. Find the *work* done in raising a mass of 2.0 kg through a vertical *distance* of 0.75 m. Take *g*, the acceleration of free fall, to be 10 m/s^2.

3. Is it possible to do work on an object that remains at rest?

(a) Yes

(b) No

4. Read the following three statements and determine whether or not they represent examples of work:

(a) A teacher applies a force to a wall and becomes exhausted.

(b) A book falls off a table and free falls to the ground.

(c) A rocket accelerates through space.

5. If Nancy pushes an object with twice the force for half the distance, she does

(a) the same work

(b) twice the work

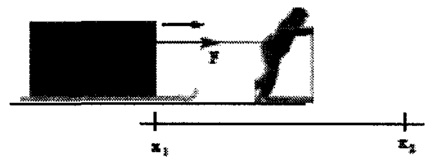
(c) half the work

(d) four times the work

To develop more knowledge concerning work-force missing link

1. How much *work* is done by a boy pulling a wagon with a horizontal *force* of 50 N for a distance of 5.4 m?

2. Determine the *work* when a *force* of 100 N is applied when pulling a sled through a distance of 20 m.



3. A man rowing a boat upstream is at rest with respect to the shore. (a) Is he doing any work? (b) If he stops rowing and moves down with the stream, is any work being done on him?

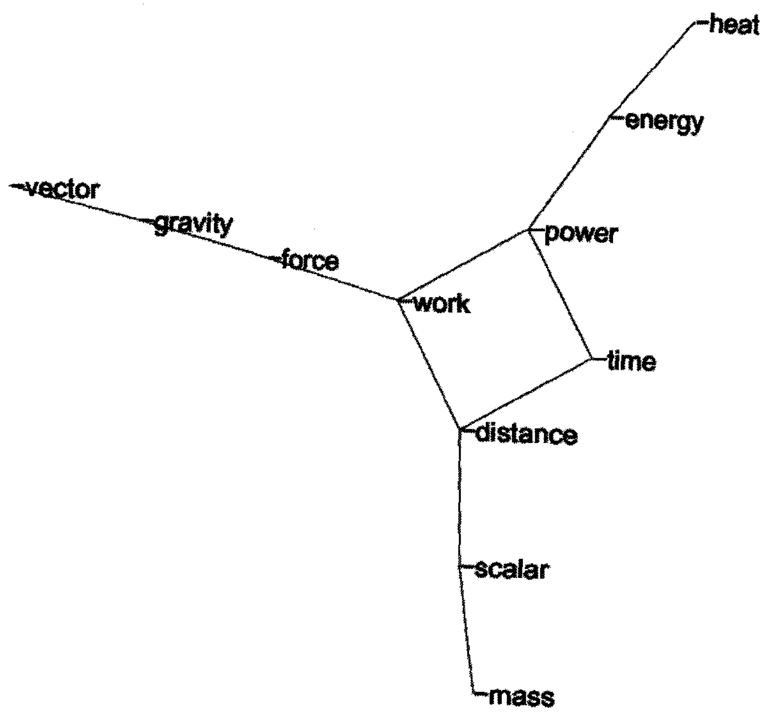
Now for another example let us consider the work concept in the *PFnet* of the student-21, as shown in Figure 3.3(b). The student-21 links the concept of work with only power, force, and distance and misses the links of work concept with energy and scalar as compared to work concept in the referent network. This student was first given the following instruction:

> "Your ratings indicate that you see the concept of *work* as being relatively strongly related to the concepts of *power, force* and *distance*. Many expert scientists think that the concept of *work* is also strongly related to the concepts of *energy* and *scalar*. Can you think of ways in which *work* is strongly related to *energy* and *scalar*?"

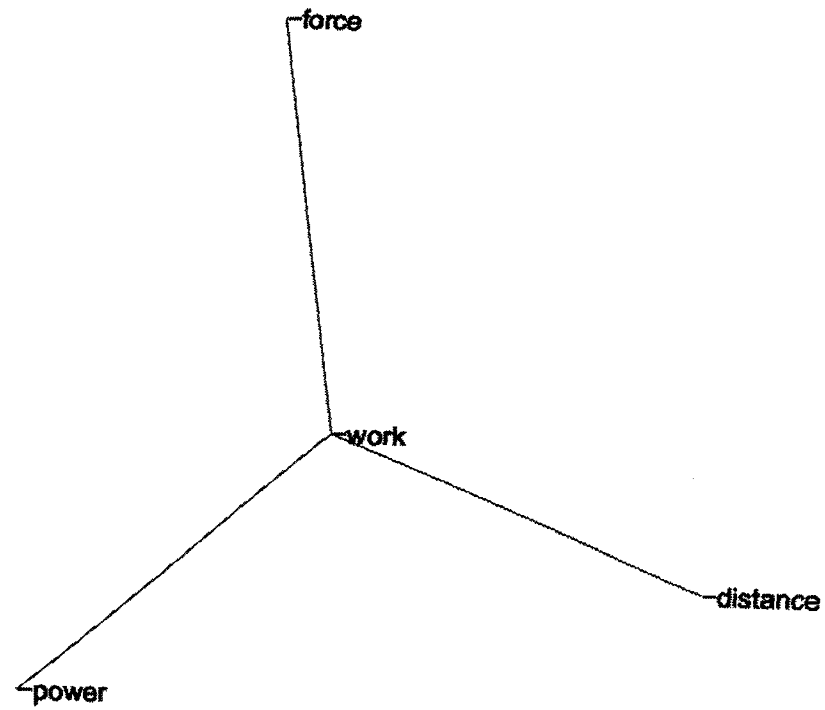
Following instructions were given to the student-21 to develop more knowledge around his missing links:

To develop more knowledge concerning work-energy missing link

1. A man lifts a 2 kg mass from the floor to a height of 1.5 m, then allows it to fall freely. Calculate (a) the work done in lifting it, (b) its kinetic energy when it has fallen half way to the floor. Assume the value of $g = 10$ m/s^2. Neglect air resistance.
2. Find the work done by a child of mass 16 kg whilst climbing to the top of a slide of vertical height 9 m. (Note that work done against gravity = *mgh* which is also equal to potential energy).

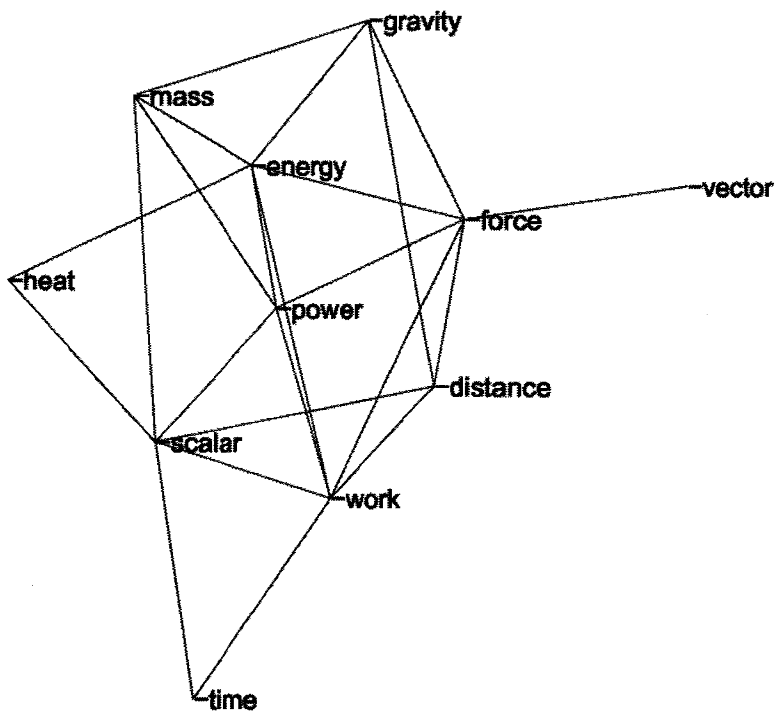


(*a*) Student-21's *PFnet*

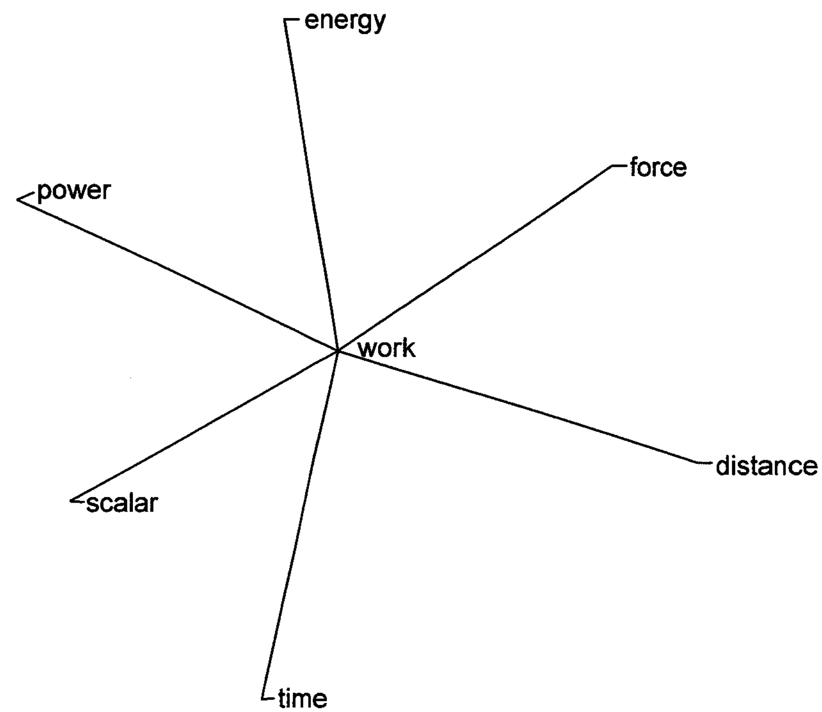


(*b*) Work concept in student-21's *PFnet*

Figure 3.3



(*a*) Student-15's *PFnet*



(*b*) Work concept in student-15's *PFnet*

Figure 3.4

3. Energy and work use the same unit of Joule because:

   (a) that is the unit chosen by the scientist named Pascal who studied heat.

   (b) energy is required to do work.

   (c) both measure the speed at which power is used.

To develop more knowledge concerning work-scalar missing link

1. Even though the *work* is the product of two vectors, force ($\vec{F}$) and displacement ($\Delta \vec{d}$), it is a *scalar* quantity. Therefore, to fully describe the work done, you only need to describe its magnitude.

Now, let us consider the work concept in the *PFnet* of the student-15, as shown in Figure 3.4(*b*). Student-15 links work concept with other concepts in exactly the same way as in the referent network with the exception of an extra link to the concept of time as compared to the referent network. Instructions and exercises given to this student were different. This student was given the following instruction:

> "Your ratings indicate that you see the concept of *work* as being relatively strongly related to the concepts of *distance, force, power, energy, scalar* and *time*. Many expert scientists do not see the concepts of *work* and *time* as being quite as strongly related. Can you think of ways in which *work* and *time* are NOT very strongly related?"

Following instructions were given to this student to develop more knowledge around his extra link:

To develop more knowledge concerning extra link of work-time

1. Does the work done in raising a box onto a platform depend on how fast it is raised?

2. Mike applied 10 N of force over 3 m in 10 seconds. Joe applied the same force over the same distance in 1 minute. Who did more work?

    (a) Mike

    (b) Joe

    (c) both did the same work

These instructions encouraged the students to compare elements of their analysis of work concept with the scientific analysis, and to identify similarities and differences. These individualized instructions and exercises required the students to confront inconsistencies between their existing notions about work concept and the content of the instructions about work concept. The conceptual confrontation enables each student to become aware of his or her existing notions and of the need to reconcile them with the scientific concepts and principles of work concept that are to be learned.

PHASE 3 OF THE EXPERIMENT

During the third phase, which was conducted a day after the second phase was over, the participants were asked to complete second ratings, using identical procedures and the same rating scale as in the first phase. The participants completed and returned the survey after about 15-20 minutes (post-intervention ratings).

CHAPTER 4: DATA ANALYSIS AND RESULTS

Trochim (1989b) examined the validity and reliability of concept mapping. According to him "the concept mapping process provides an accurate representation of what people are thinking (*i.e.,* reliability and validity)". However Trochim insists that the validity and reliability of concept mapping needs further investigations. According to Trochim (1989b) *validity* is meant to refer to "the degree to which a map accurately reflects reality" and *reliability* should be understood as "the degree to which a map is *repeatable*". To address *validity* of concept mapping, the similarity indices of mass and gravity concepts (control concepts) in the pathfinder networks of the students were also checked for improvement in addition to the similarity index of work concept (treatment concept). The *reliability* could mean the overall degree of repeatability (*e.g.,* similarity across maps) or the reliability across a specific concept in the process of concept mapping. A researcher could look at the degree to which the same participants generate similar results on multiple occasions. Therefore, in the experiment, three pair-wise comparisons were repeated at the end of the questionnaire during phase 1 and phase 3, to check the reliability of the reply by the students.

RELIABILITY OF THE RATINGS

To check reliability of the ratings, Pearson correlation coefficients r were calculated from paired scores for the three comparisons which first appeared in the questionnaire and then repeated at the end for each participant's ratings during the first and second completion of the task. This provided a measure of the *reliability* and *stability* of one's structural knowledge across time (Trumpower, 2003). The study indicated significant consistency in the participants' ratings.

The students' pre-intervention rating had a mean correlation coefficient of 0.80 which increased to 0.81 in the post-intervention ratings. The experts' ratings had a mean correlation coefficient of 1.0. Table 4.1 shows the Pearson correlation coefficients of the participants in the study. In Table 4.2, each row shows the number of participants who are in a certain range of the Pearson correlation coefficient.

Table: 4.1: Pearson correlation coefficients of the participants

Participants	Average Pearson correlation coefficients	
	1st ratings	2nd ratings
Experts	1	—
Male students	0.93	0.95
Female students	0.77	0.75
Overall students	0.80	0.81

Table 4.2: Number of participants in a certain range of Pearson correlation coefficient

	Participants	**Pearson correlation coefficients**			
		Excellent	good	acceptable	poor
		$r \geq 0.8$	$0.6 \leq r < 0.8$	$0.4 < r < 0.6$	$-1 \leq r \leq 0.4$
1st Ratings	Experts	2	0	0	0
	Male students	11	1	0	2
	Female students	6	0	0	0
	Overall students	17	1	0	2
2nd Ratings	Male students	13	0	1	2
	Female students	7	0	0	0
	Overall students	20	0	1	2

One of the limitations of Pearson correlation coefficient is that if any of the two or both variable remains constant, then the average value of variable(s) would be the same as all the values of a variable across the column and it will make denominator in the equation, to calculate *r,* equal to zero. For example, it is not possible to calculate the correlation between two columns which are like:

2	3	or like	5	5
2	2		5	5
2	2		5	5

There were a total of 6 ratings for which the Person correlation coefficient was not calculated to check the reliability, because of this limitation. Out of those 6 entries of 3 pairs of terms each, only the rating for 1 pair changed in 4 entries, and that too only by a value of 1 on the rating scale, whereas for the rest of 2 entries, both the 3 pairs of terms rated remained same and constant.

PROXIMITY MATRIX

The degree of similarity in the student and referent networks at pre- and post-intervention serves as a baseline for assessing pre- and post-intervention differences. To calculate similarity indices, a proximity matrix was constructed for each participant using raw proximity data collected in phase 1 and 3 of the experiment. In this proximity matrix all possible pairs of concepts were represented. A proximity matrix has as many rows and columns as there are concepts in a list. The diagonal elements of this matrix represent an item's similarity to itself. The top half of the proximity matrix (called upper half-matrix) is the mirror image of the bottom half (called lower half-matrix). The readings from a pair-wise ratings are typically represented as an upper half-matrix. One typical example of upper-half matrix is shown in Figure 4.1, which lists all the concepts used in the study.

TERMS	Distance	Energy	Force	Gravity	Heat	Mass	Power	Scalar	Time	Vector	Work
Distance	-	3	2	5	4	4	1	5	2	1	2
Energy		-	3	2	5	5	4	1	1	1	5
Force			-	5	2	5	4	1	3	5	5
Gravity				-	1	1	2	1	1	5	4
Heat					-	3	2	1	1	1	4
Mass						-	4	5	1	1	2
Power							-	5	4	1	5
Scalar								-	5	3	5
Time									-	1	2
Vector										-	1
Work											-

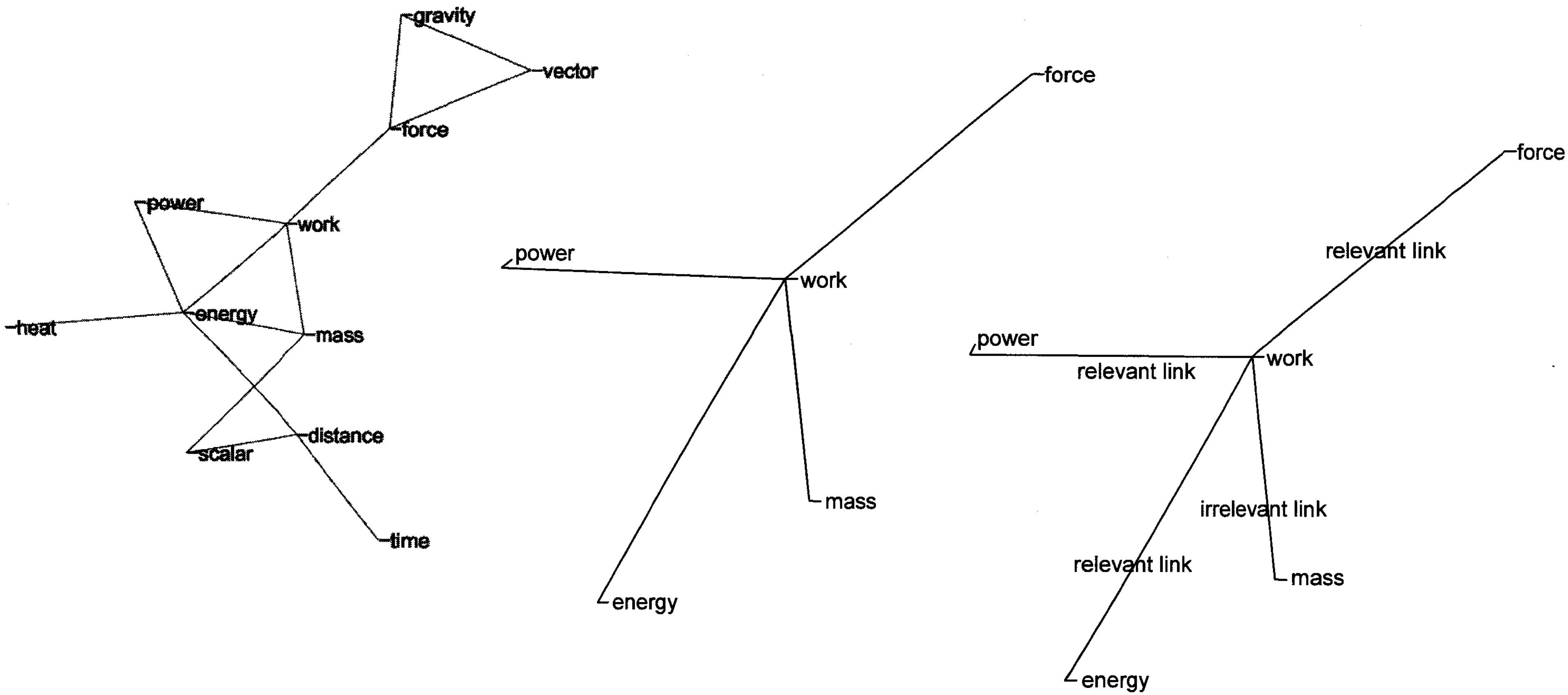
Figure 4.1: Upper-half proximity matrix of "work, energy, and power" concepts

The rating of 5 indicates that two concepts are highly related while the rating of 1 indicates that two concepts are unrelated. The proximity matrix is considered as the primary structure of the conceptual domain because it provides information about how participants relate the concepts.

DATA ENTRY

The raw data were entered into a Microsoft Excel 2007 spreadsheet and data from each column of the spreadsheet was copied into individual proximity files to create a proximity matrix for each participant. The researcher used Microsoft Excel 2007 to average the experts' pair-wise ratings and then the averaged value was used to construct a proximity matrix. The data from this proximity matrix was used as an input for KNOT software to generate referent *PFnet* shown in Figure 3.1(*a*). *KNOT* software (Goldsmith & Davenport, 1990) reduces the raw proximity data to a least-weighted path that links all of the terms (Dearholt & Schvaneveldt, 1990). One of the expert participants, who was a grade 11 physics instructor at a public high school of Ottawa, visually inspected the referent network and agreed that it was the valid representation of how he conceptualizes relationships among the different concepts in the physics domain of work, energy, and power. One student left 2 and another student left 1 of the 58 pair-wise ratings blank. A rating of 3 (*neutral*) was entered for all the blanks under the assumption that a neutral response best reflects the undecided response by the students for a particular rating. The KNOT software was also used to transform the students' ratings into *PFnets*. These *PFnets* of the students generated through first- and second-ratings are included as Appendix I.

To test the hypothesis 1 (stated earlier in the chapter 2) the similarity indices of students' *PFnets* for pre- and post-intervention were calculated by comparing these networks with the referent *PFnet*. In the next step, *work concept* was picked as the central concept because this concept was linked to most of the concepts (5 concepts here) in the referent network. Central concept, therefore, could be more quickly retrieved from memory and thus, is believed to reflect attitudes that are more salient and are more accessible during decision-making (Meyer and Schvaneveldt, 1976). This central concept and its links with other concepts in a student's network were compared to the same concept in the referent network to calculate another similarity index. This similarity index was calculated manually because there is no option to work at a subset level in KNOT software. Moreover, the number of relevant and irrelevant links in the central concept (*i.e.,* the concept of work) in a student's network can be compared to the number of relevant links around the central concept in the referent network. This would be a kind of follow-up test because the similarity index of work concept can increase either by the increase of relevant links or by the decrease of irrelevant links in the students' networks or both. This similarity index was also calculated manually. Figure 4.2 illustrates the different ways of measuring similarity. In the phase 2 of the experiment, individualized instructions were given to the students. These instructions were only about missing and irrelevant links in work concept in students' *PFnets*. Therefore, the hypothesis 2 (stated earlier in the chapter 2) is that the similarity



(a) A *PFnet* (b) Work concept (c) Relevant and irrelevant links in work concept

Figure 4.2: Levels of similarity in pathfinder networks

index of work concept in the pathfinder network of the students will increase from pre- to post-intervention phase.

In order to address issues of validity (Creswell, 2007), two other concepts, the concepts of mass and gravity, were picked for analysis as control concepts. The reason for picking these two concepts was that these concepts were least related to the concept of work (treatment concept) in the referent network. No feedback was given to the students around these two concepts. The hypothesis 3 (stated earlier in the chapter 2) about these concepts is that there will be a statistically non-significant difference between pre-intervention and post-intervention similarity indices of mass and gravity concepts in the pathfinder networks of the students. To evaluate this hypothesis, mass and gravity concepts in a student's network were compared to the same concepts in the referent network to calculate the similarity index for pre- and post-intervention phase. Moreover, the numbers of relevant and irrelevant links in mass and gravity concepts in the students' networks were also compared to the number of relevant links in mass and gravity concepts in the referent network.

Parameter values of $r = \infty$ and $q = n - 1$ were used. This reduced the number of links within a network to a manageable number, as opposed to having a huge number of links. In a network of 11 concepts where each concept can be linked to all other concepts, the results would be 54 links (as shown in Figure 2.2*a*). If the values of the parameter are set to $r = \infty$ and $q = n - 1$, the software will only retain those concepts that are highly related as compared to other concepts in the list and as a result the number of links will be reduced considerably (as shown in Figure 2.2*b*).

ANALYSIS OF SIMILARITY INDICES OF *PFNETS* OF THE PARTICIPANTS

The pre- and post-intervention similarity indices of each student's *PFnet* were calculated to test the hypothesis 1. To determine whether there is a significant increase in the similarity indices of the students' *PFnets* from pre- to post-intervention phase, one-way analysis of variance (ANOVA) within-subjects was computed using Statistical Package for the Social Sciences (SPSS) version 15.0 for Windows. As described in the methodology section, the rating scale was based on 5 exact intervals to measure the relatedness of the pairs of concepts and was directly comparable across participants. Thus they were interval in nature, and ANOVA was appropriate. The likelihood of finding significant results was increased because of the large number of participants ($N = 24$). Given the exploratory nature of this analysis, no adjustment to a standard alpha level of 0.05 was made. The same value of alpha level was used to define statistical significance for all calculations in this study, unless otherwise stated. From ANOVA, pre-intervention and post-intervention similarity indices of students' *PFnets* yielded significant differences among them, with $F(1, 23) = 17.04$; $p = 0.00$. The pre-intervention average similarity index of the students was 0.45 ($SD = 0.11$) which increased to 0.56 ($SD = 0.12$) in the post-intervention ratings. This finding argues that the similarity of the students' *PFnets* with the referent *PFnet* increased or, in other words, the presence of misconceptions decreased substantially because of the intervention (hypothesis 1). This trend is highlighted in a graph shown in Figure 4.3. The graph also shows that misconceptions were very evenly distributed among the students.

To test the hypothesis 1 separately for male ($N = 17$) and female ($N = 7$) students, within-subjects ANOVA was carried out separately for male and female students. It was observed that the male students differed from the female students as far as reduction of the number of

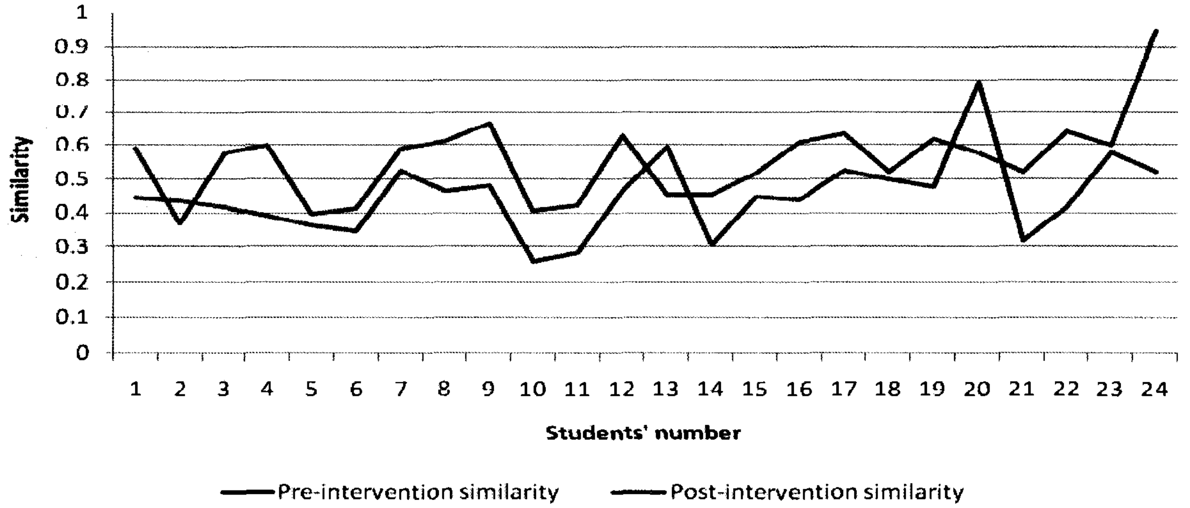


Figure 4.3: Graph showing pre- and post-intervention similarity of students' *PFnets* with the referent *PFnet*

misconceptions is concerned. The pre-intervention and post-intervention similarity indices of the male students' *PFnets* yielded significant differences among them, with $F(1, 16) = 16.28$; $p = 0.00$. The pre-intervention average similarity index of the male students was 0.44 ($SD = 0.13$) which increased to 0.57 ($SD = 0.13$) in the post-intervention ratings. These results showed that the presence of misconceptions decreased substantially because of the intervention among the male students. On the other hand, the pre-intervention and post-intervention similarity indices of the female students' *PFnets* yielded the value of $F(1, 6) = 1.92$; $p = 0.22$. This is statistically non-significant because the value of p is more than the normal criterion of 0.05. Although the pre-intervention average similarity index of the female students was 0.47 ($SD = 0.09$) which increased to 0.54 ($SD = 0.10$) in the post-intervention ratings, it cannot be extended to the general female student population. This statistically non-significant result was perhaps due to the lesser number of female participants in the sample. Therefore, it cannot be concluded definitely for the female students that the presence of misconceptions decreased because of the intervention.

ANALYSIS OF SIMILARITY INDEX OF WORK CONCEPT IN THE *PFNETS* OF THE PARTICIPANTS

Each student's *PFnet* was also investigated around work concept. The pre- and post-intervention similarity indices of work concept in the students' *PFnets* were calculated with reference to work concept of in the referent *PFnet*. To determine whether there is a significant difference among the similarity indices of work concept in the students' *PFnets* before and after intervention, one-way analysis of variance (ANOVA) within-subjects was computed. From that ANOVA, pre-intervention and post-intervention similarity indices of work concept in the students' *PFnets* yielded significant differences among them, with $F(1, 23) = 22.27; p = 0.00$. The pre-intervention average similarity index of the students was 0.53 ($SD = 0.18$) which increased to 0.76 ($SD = 0.18$) in the post-intervention ratings. This finding argues that the similarity of work concept in the students' *PFnets* increased with the referent *PFnet* or, in other words, the presence of misconceptions around the concept of work decreased substantially because of the intervention (hypothesis 2). This trend is highlighted in a graph shown in Figure 4.4.

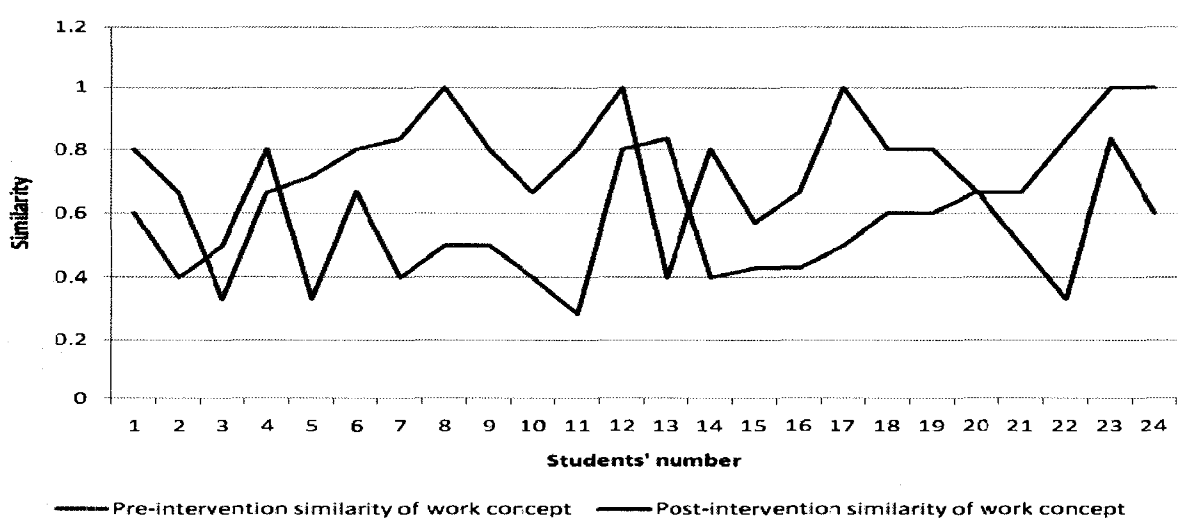


Figure 4.4: Graph showing pre- and post-intervention similarity of work concept of students' *PFnets* with the referent *PFnet*

To test the hypothesis 2 separately for male ($N = 17$) and female ($N = 7$) students, within-subjects ANOVA was carried out separately for male and female students. It was again observed that the male students differ from the female students as far as reduction of the number of misconceptions around work concept is concerned. The pre-intervention and post-intervention similarity indices of work concept in the male students' *PFnets* yielded significant differences among them, with $F(1, 16) = 22.17$; $p = 0.00$. The pre-intervention average similarity index of the male students was 0.53 ($SD = 0.19$) which increased to 0.77 ($SD = 0.18$) in the post-intervention ratings. This showed that the presence of misconceptions around work concept decreased substantially because of the intervention among the male students. On the other hand, the pre-intervention and post-intervention similarity indices of the female students' *PFnets* yielded the value of $F(1, 6) = 2.86$; $p = 0.14$. This is statistically non-significant. Although the pre-intervention average similarity index of the female students was 0.54 ($SD = 0.16$) which increased to 0.74 ($SD = 0.19$) in the post-intervention ratings, it cannot be extended to the general female student population. This statistically non-significant result may be due to the lesser number of female participants in the sample. Therefore, this cannot be concluded definitely for the female students that the presence of misconceptions around work concept decreased because of the intervention.

ANALYSIS OF RELEVANT AND IRRELEVANT LINKS IN WORK CONCEPT IN THE *PFNETS* OF THE PARTICIPANTS

To further test the hypothesis 2, pre- and post-intervention numbers of the relevant and irrelevant links in work concept were calculated for each student. Table 4.3 shows the number of pre- and post-intervention relevant and irrelevant links in work concept of the students.

Table: 4.3: Pre- and post-intervention relevant and irrelevant links in work concept of the students

Links		Pre-intervention			Post-intervention		
		male	female	total	male	female	total
Relevant links	work-force	12	5	17	15	6	21
	work-distance	11	5	16	17	6	23
	work-scalar	8	2	10	13	4	17
	work-energy	11	5	16	12	5	17
	work-power	10	4	14	15	7	22
	Mean	3.06	3.00	3.04	4.24	4.00	4.17
Irrelevant links	work-mass	4	1	5	2	1	3
	work-time	4	1	5	3	2	5
	work-heat	2	0	2	3	0	3
	work-gravity	1	0	1	1	0	1
	work-vector	2	2	4	1	0	1
	Mean	0.76	0.57	0.71	0.59	0.43	0.54

Note. The numbers in the table are frequencies (except for the rows labeled "Mean" which indicate the mean number of links per student). Total number of the participants were 24 (male = 17 and female = 7).

To determine whether there is a significant difference among the relevant and irrelevant links in work concept of the students' *PFnets* as compared to the referent network before and after the intervention, a 2 (time: pre-intervention or post-intervention) × 2 (links: relevant links or irrelevant links) two-way within-subjects analysis of variance (ANOVA) was computed. This two-way ANOVA with repeated measures revealed a significant interaction between both factors, $F(1, 23) = 21.44$; $p = 0.00$. Simple effect analysis indicated that the presence of misconceptions around work concept decreased because of the increase in relevant links in work concept, $F(1, 23) = 16.39$; $p = 0.00$. The mean of pre-intervention relevant links in work concept was 3.04 ($SD = 0.91$) which increased to 4.17 ($SD = 0.82$) in the post-intervention ratings (hypothesis 2). This trend is highlighted in a graph shown in Figure 4.5. Although, the mean of pre-intervention irrelevant links in work concept was 0.71 ($SD = 0.69$) which decreased to 0.54 ($SD = 0.66$) in the post-intervention ratings, the simple effect test revealed a non-significant decrease of irrelevant links, $F(1, 23) = 1.00$; $p = 0.33$ on the misconceptions of the students. However, this trend of decrease in irrelevant links in work concept is highlighted in a graph shown in Figure 4.6.

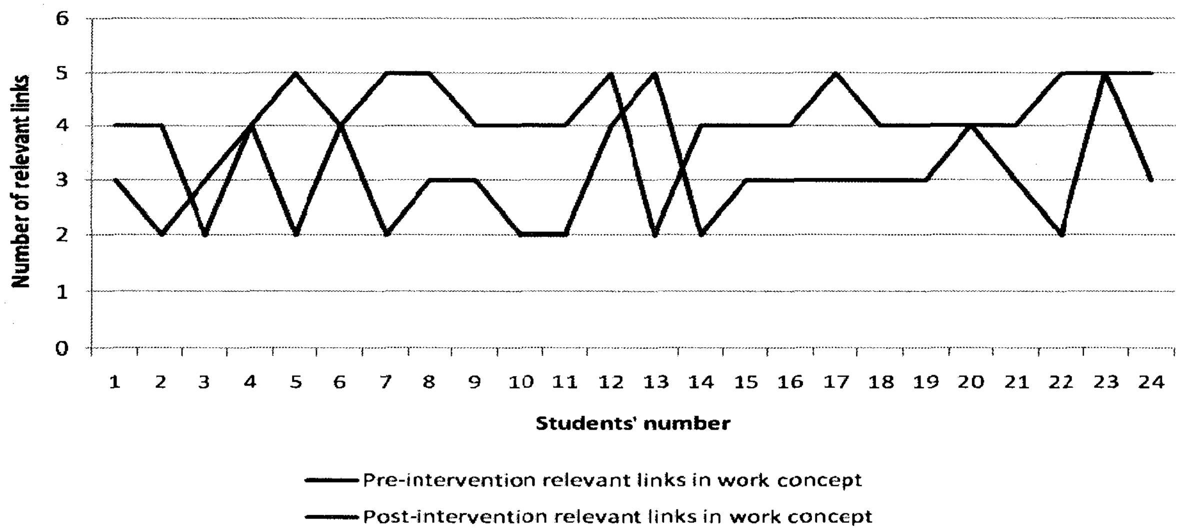


Figure 4.5: Graph showing pre- and post-intervention relevant links in work concept in students' *PFnets* when compared to the referent *PFnet*

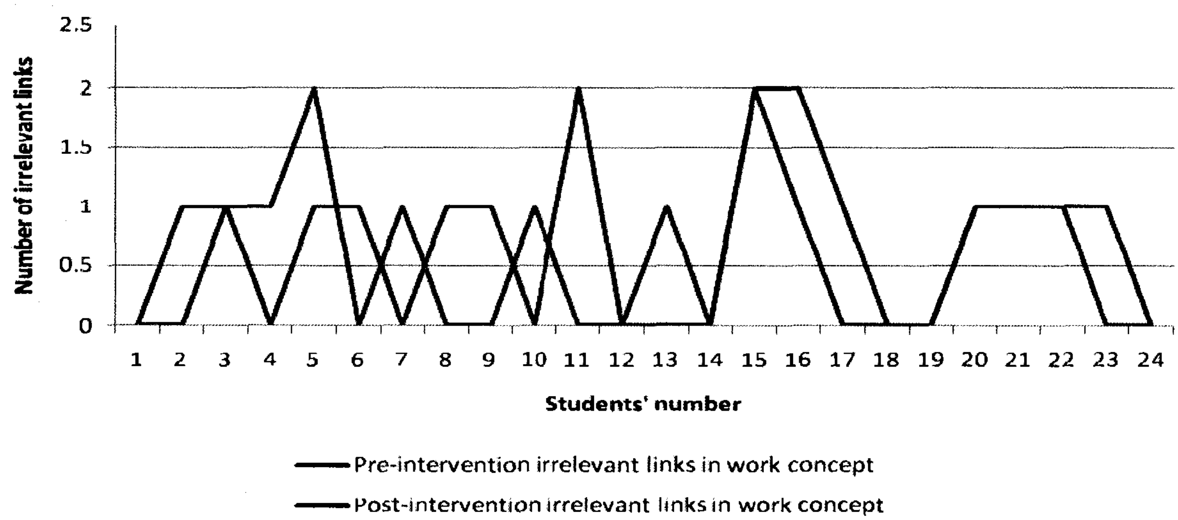


Figure 4.6: Graph showing pre- and post-intervention irrelevant links in work concept in students' *PFnets* when compared to the referent *PFnet*

To test the conclusion separately for male ($N = 17$) and female ($N = 7$) students, two-way within-subjects ANOVA was carried out separately for male and female students. This two-way ANOVA with repeated measures showed a significant interaction between both factors, $F(1, 16) = 19.24$; $p = 0.00$ for male students. Simple effect analysis indicated that the presence of misconceptions around work concept decreased because of the increase in relevant links in work concept, $F(1, 16) = 18.39$; $p = 0.00$. The mean of pre-intervention relevant links in work concept was 3.06 ($SD = 0.90$) which increased to 4.24 ($SD = 0.75$) in the post-intervention ratings. Although, the mean of pre-intervention irrelevant links in work concept for male students was 0.76 ($SD = 0.75$) which decreased to 0.59 ($SD = 0.71$) in the post-intervention ratings, the simple effect test revealed a non-significant decrease of irrelevant links, $F(1, 16) = 0.679$; $p = 0.42$ on the misconceptions of the male students. This finding and significant interaction effect argue that the relevant links in work concept in the male students' *PFnets* increased when compared to the referent *PFnet* or, in other words, the presence of misconceptions around the concept of work decreased substantially because of the intervention (hypothesis 2). On the other hand, for female students ANOVA yielded statistically non-significant main effect of time [$F(1, 6) = 0.94$; $p = 0.37$] but significant main effect of links [$F(1, 6) = 252.00$; $p = 0.00$] on similarity indices of work concept of the students and statistically non-significant interaction between both factors [$F(1, 6) = 3.25$; $p = 0.12$]. Although, the mean of pre-intervention relevant links in work concept was 3.00 ($SD = 1.00$) which increased to 4.00 ($SD = 1.00$) in the post-intervention ratings, and the mean of pre-intervention irrelevant links in work concept was 0.57 ($SD = 0.53$) which decreased to 0.43 ($SD = 0.53$) in the post-intervention ratings, the results shows that female students did not improve because of the intervention. Statistically non-significant main effect of time is perhaps due to the lesser number of female participants in the sample. Therefore, this cannot be concluded definitely for the female students that the presence of misconceptions decreased because of the intervention. The issue will be further discussed in the chapter 5.

ANALYSIS OF SIMILARITY INDICES OF MASS AND GRAVITY CONCEPTS IN THE *PFNETS* OF THE PARTICIPANTS

To address the validity of the research process, *PFnet* of each student was also investigated around mass and gravity concepts (control concepts). The pre- and post-intervention similarity indices of mass and gravity concepts in the students' *PFnets* were calculated with reference to mass and gravity concepts in the referent *PFnet*. To determine whether there is a significant difference among the similarity indices of mass and gravity concepts in the students' *PFnets* before and after the intervention, one-way analysis of variance (ANOVA) within-subjects was computed separately for mass and gravity concepts. From that ANOVA, pre-intervention and post-intervention similarity indices of mass concept in the students' *PFnets* yielded non-significant differences among them, with $F(1, 23) = 3.68$; $p = 0.07$. The pre-intervention average similarity index of the students was 0.49 ($SD = 0.26$) which increased to 0.59 ($SD = 0.23$) in the post-intervention ratings. Moreover, pre-intervention and post-intervention similarity indices of gravity concept in the students' *PFnets* also yielded non-significant differences among them, with $F(1, 23) = 3.05$; $p = 0.09$. The pre-intervention average similarity index of the students was 0.54 ($SD = 0.21$) which increased to 0.64 ($SD = 0.16$) in the post-intervention ratings. These findings show that although the similarity of both mass and gravity concepts in the students' *PFnets* increased with the referent *PFnet*, it is statistically non-significant and results cannot be extended to the general student population (hypothesis 3). This trend is highlighted in the graphs shown in Figure 4.7 and Figure 4.8. These graphs show that increase in the similarity indices of mass and gravity concepts is not consistent, although the output of F tests shows that there is a slight increase in the mean similarity index of both mass and gravity concepts after the intervention.

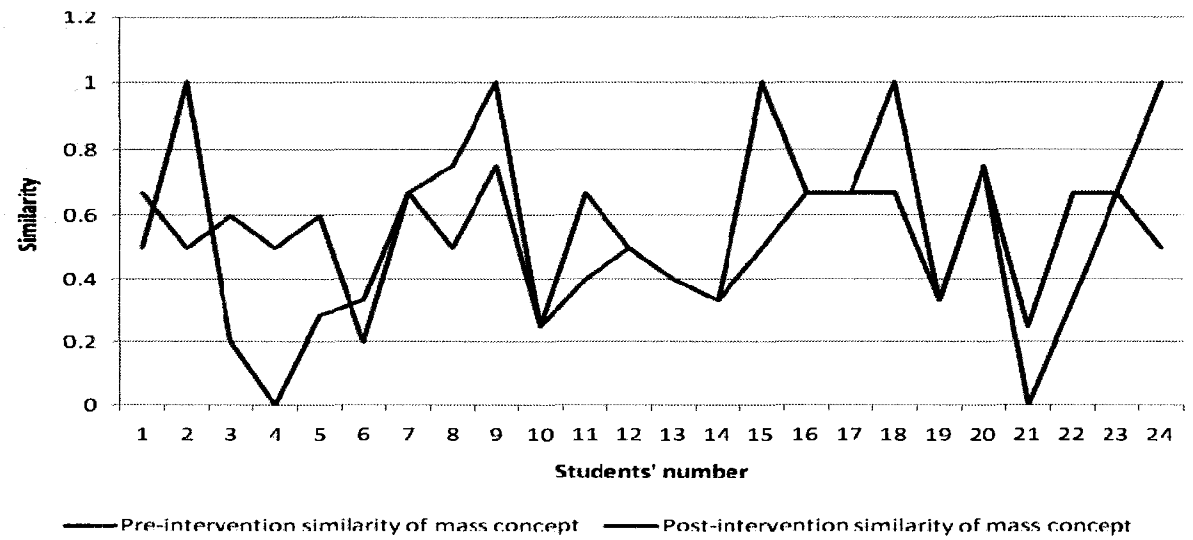


Figure 4.7: Graph showing pre- and post-intervention similarity of mass concept of students' *PFnets* with the referent *PFnet*

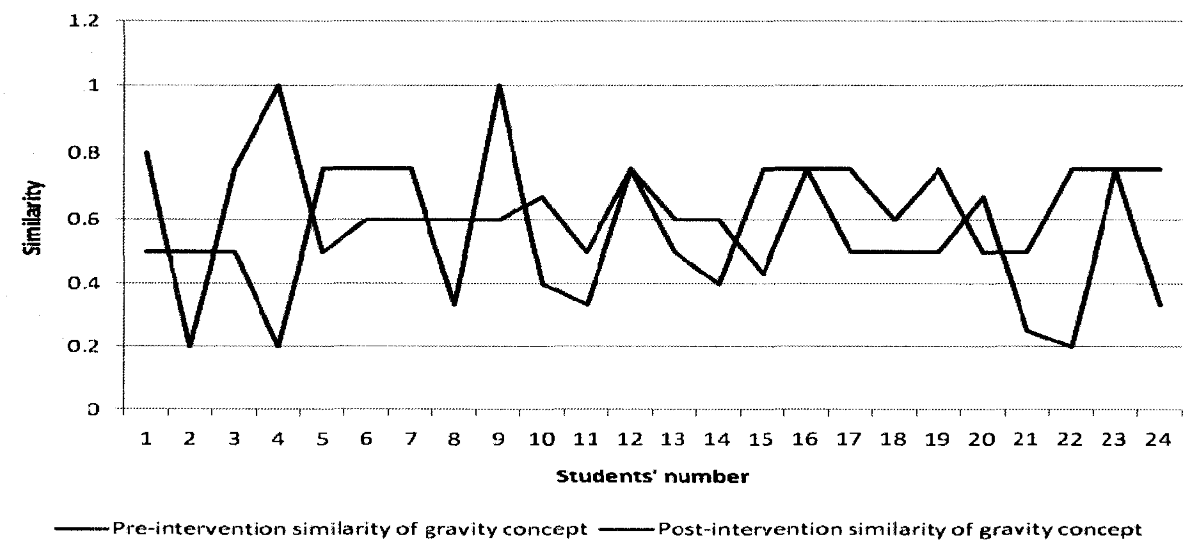


Figure 4.8: Graph showing pre- and post-intervention similarity of gravity concept of students' *PFnets* with the referent *PFnet*

To test the hypothesis 3 separately for male ($N = 17$) and female ($N = 7$) students, within-subjects ANOVA was carried out separately for male and female students. From that ANOVA, pre-intervention and post-intervention similarity indices of mass concept in the male students' *PFnets* yielded non-significant differences among them, with $F(1, 16) = 3.77$; $p = 0.07$. The pre-intervention average similarity index of the male students was 0.49 ($SD = 0.25$) which increased to 0.61 ($SD = 0.22$) in the post-intervention ratings. Moreover, pre-intervention and post-intervention similarity indices of gravity concept in the male students' *PFnets* also yielded non-significant differences among them, with $F(1, 16) = 1.41$; $p = 0.25$. The pre-intervention average similarity index of the male students was 0.58 ($SD = 0.22$) which increased to 0.66 ($SD = 0.15$) in the post-intervention ratings. On the other hand, pre-intervention and post-intervention similarity indices of mass concept in the female students' *PFnets* yielded non-significant differences among them, with $F(1, 6) = 0.29$; $p = 0.61$. The pre-intervention average similarity index of the female students was 0.49 ($SD = 0.32$) which increased to 0.55 ($SD = 0.26$) in the post-intervention ratings. Moreover, pre-intervention and post-intervention similarity indices of gravity concept in the female students' *PFnets* also yielded non-significant differences among them, with $F(1, 6) = 1.88$; $p = 0.22$. The pre-intervention average similarity index of the female students was 0.44 ($SD = 0.15$) which increased to 0.58 ($SD = 0.20$) in the post-intervention ratings. These findings show that although the similarity of both mass and gravity concepts in the male and female students' *PFnets* increased with referent *PFnet*, it is statistically non-significant and results cannot be extended to the general student population (hypothesis 3). Therefore, for male and female students, the presence of misconceptions around mass and gravity concepts did not decrease because of intervention as individualized instructions, which were given to the students, were only around the concept of work. The slight increase in the mean similarity may be due to the practice effect.

ANALYSIS OF RELEVANT AND IRRELEVANT LINKS IN MASS AND GRAVITY CONCEPTS IN THE *PFNETS* OF THE PARTICIPANTS

To further test the hypothesis 3, pre- and post-intervention numbers of the relevant and irrelevant links in mass and gravity concepts were calculated for each student. Table 4.4 shows the number of pre- and post-intervention relevant and irrelevant links in mass concept of the students. Table 4.5 shows the number of pre- and post-intervention relevant and irrelevant links in gravity concept of the students.

Table: 4.4: Pre- and post-intervention relevant and irrelevant links in mass concept of the students

Links		Pre-intervention			Post-intervention		
		male	female	total	male	female	total
Relevant links	mass-force	7	2	9	10	2	12
	mass-gravity	15	3	18	17	4	21
	mass-scalar	9	6	15	10	7	17
	Mean	1.82	1.57	1.75	2.18	1.86	2.08
Irrelevant links	mass-power	5	1	6	3	2	5
	mass-energy	5	1	6	4	1	5
	mass-work	4	1	5	2	1	3
	mass-heat	1	0	1	1	0	1
	mass-distance	1	0	1	1	0	1
	mass-vector	0	0	0	1	0	1
	Mean	0.94	0.43	0.79	0.71	0.57	0.67

Note. The numbers in the table are frequencies (except for the rows labeled "Mean" which indicate the mean number of links per student). Total number of the participants were 24 (male = 17 and female = 7).

Table: 4.5: Pre- and post-intervention relevant and irrelevant links in gravity concept of the students

Links		Pre-intervention			Post-intervention		
		male	female	total	male	female	total
Relevant links	gravity-force	16	7	23	14	7	21
	gravity-distance	7	1	8	9	1	10
	gravity-mass	15	3	18	17	4	21
	gravity-vector	7	2	9	12	5	17
	Mean	2.65	1.86	2.42	3.06	2.43	2.88
Irrelevant links	gravity-heat	1	0	1	1	0	1
	gravity-power	0	0	0	1	1	2
	gravity-energy	7	2	9	6	1	7
	gravity-scalar	3	0	3	1	0	1
	gravity-time	2	0	2	2	0	2
	gravity-work	1	0	1	1	0	1
	Mean	0.82	0.29	0.67	0.71	0.29	0.58

Note. The numbers in the table are frequencies (except for the rows labeled "Mean" which indicate the mean number of links per student). Total number of the participants were 24 (male = 17 and female = 7).

To determine whether there is a significant difference among the relevant and irrelevant links in mass and gravity concepts of the students' *PFnets* as compared to the referent network before and after the intervention, a 2 (time: pre-intervention or post-intervention) × 2 (links: relevant links or irrelevant links) two-way within-subjects analysis of variance (ANOVA) was computed separately for mass and gravity concepts. The two-way ANOVA with repeated measures for mass concept revealed a non-significant interaction between both factors, $F(1, 23) = 3.06; p = 0.09$. Main effects analyses indicated that the presence of misconceptions around mass concept decreased because of the increase in relevant links and decrease in irrelevant links in mass concept, $F(1, 23) = 35.53; p = 0.00$. Time factor, on the other hand, exhibited equal change during the pre-intervention and post-intervention, $F(1, 23) = 1.09; p = 0.31$, *ns*. Furthermore, gravity concept also revealed a non-significant interaction between both factors, $F(1, 23) = 2.70; p = 0.11$. Main effects analyses indicated that the presence of misconceptions around gravity concept decreased because of the increase in relevant links and decrease in irrelevant links in gravity concept, $F(1, 23) = 192.02; p = 0.00$. Again time factor exhibited equal change during the pre-intervention and post-intervention, $F(1, 23) = 1.63; p = 0.21$, *ns*. There is a non-significant interaction of the factors of *time* and *links* for both mass and gravity concepts. Further, there is a non-significant effect of the time factor for both mass and gravity concepts. From this output we may conclude that the students did not improve over time around mass concept and the same inference is true for gravity concept.

The finding also shows that the relevant links in mass and gravity concepts in the students' *PFnets* increased and irrelevant links decreased when compared to the referent *PFnet* or, in other words, the presence of misconceptions around mass and gravity concepts also decreased because of the intervention. This trend of increase in relevant links is highlighted in a graph shown in Figure 4.9 for the concept of mass and in Figure 4.10 for the concept of gravity. The trend of decrease in irrelevant links in mass and gravity concepts is highlighted in a graph shown in Figure 4.11 and Figure 4.12 respectively. However, because of the non-significant interaction and non-significant main effect of time, these results cannot be extended to the general student population.

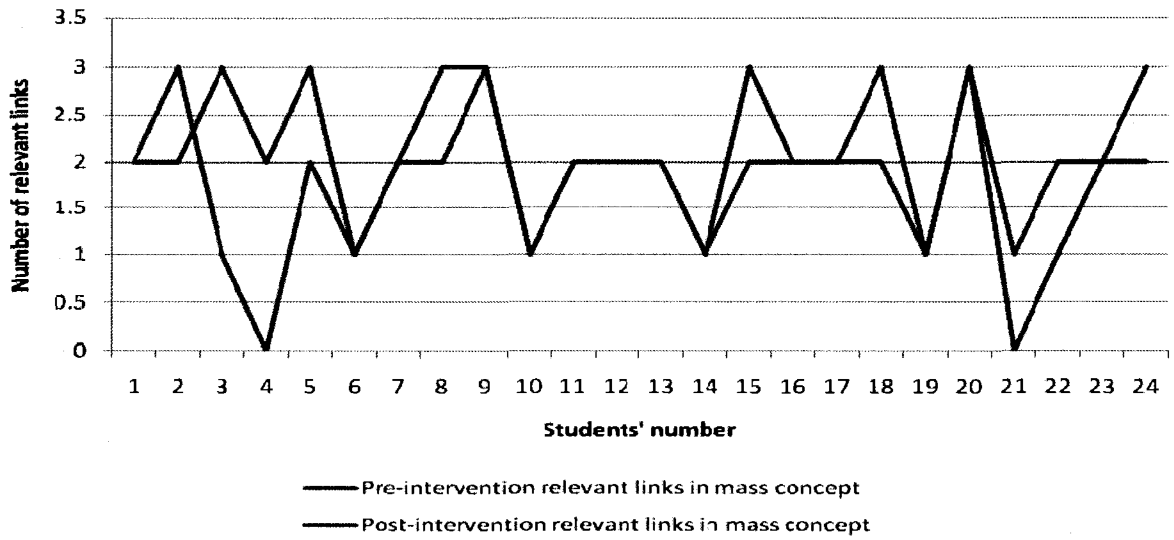


Figure 4.9: Graph showing pre- and post-intervention relevant links in mass concept in students' *PFnets* when compared to the referent *PFnet*

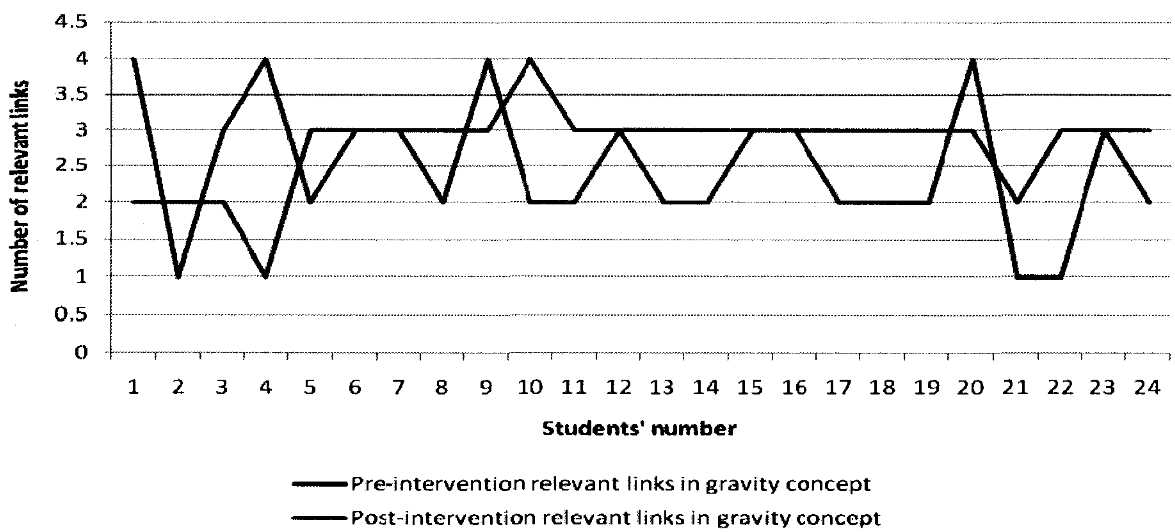


Figure 4.10: Graph showing pre- and post-intervention relevant links in gravity concept in students' *PFnets* when compared to the referent *PFnet*

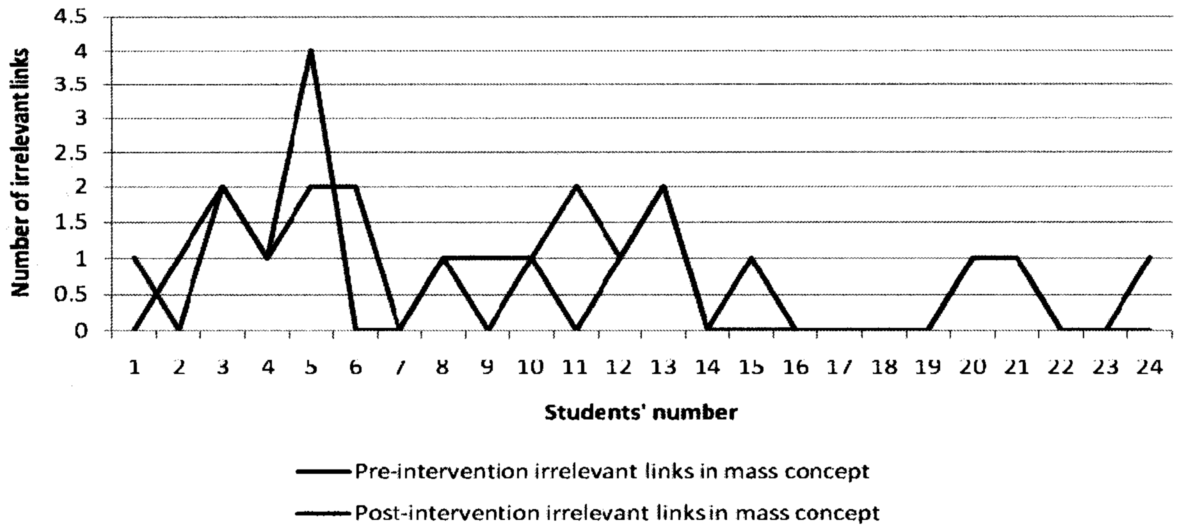


Figure 4.11: Graph showing pre- and post-intervention irrelevant links in mass concept in students' *PFnets* when compared to the referent *PFnet*

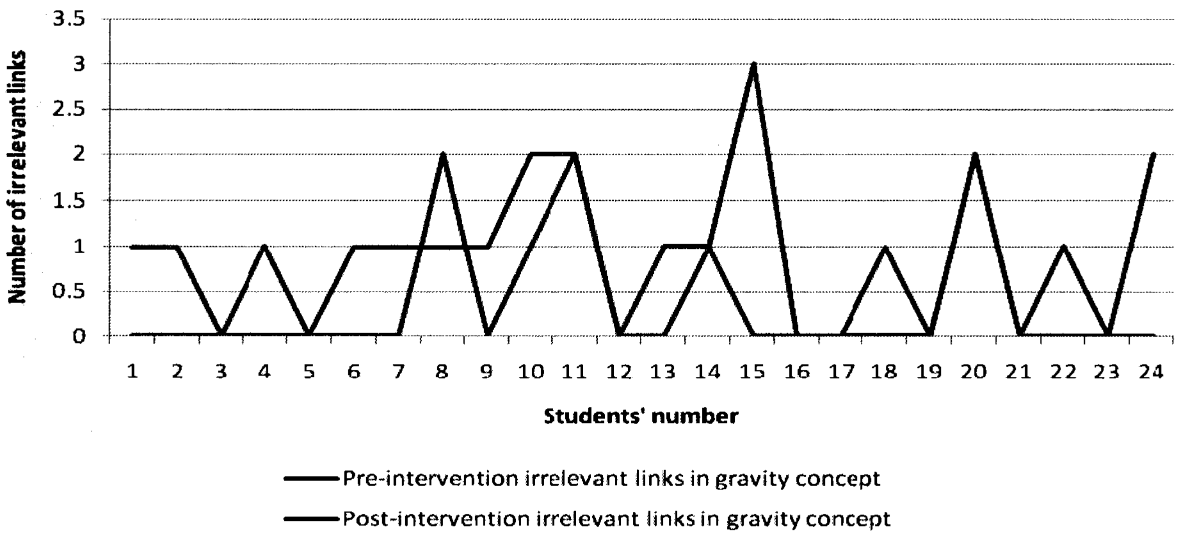


Figure 4.12: Graph showing pre- and post-intervention irrelevant links in gravity concept in students' *PFnets* when compared to the referent *PFnet*

To test the conclusion separately for male ($N = 17$) and female ($N = 7$) students, two-way within-subjects ANOVA was carried out separately for male and female students. From that ANOVA, pre-intervention and post-intervention relevant and irrelevant links in mass concept in the male students' *PFnets* yielded a non-significant interaction between both factors, $F(1, 16) = 3.13; p = 0.10$. Main effects analyses indicated that the presence of misconceptions around mass concept decreased because of the increase in relevant links and decrease in irrelevant links in mass concept, $F(1, 16) = 26.02; p = 0.00$. Time factor, on the other hand, exhibited equal change during the pre-intervention and post-intervention, $F(1, 16) = 0.19; p = 0.67$, *ns.* Moreover, the pre-intervention and post-intervention relevant and irrelevant links in mass concept in the female students' *PFnets* also yielded a non-significant interaction between both factors, $F(1, 6) = 0.13; p = 0.74$. Main effects analyses indicated that the presence of misconceptions around mass concept decreased because of the increase in relevant links and decrease in irrelevant links in mass concept, $F(1, 6) = 8.34; p = 0.03$. Time factor (from pre-intervention to post-intervention), on the other hand, exhibited non-significant effect, $F(1, 6) = 4.50; p = 0.08$.

Furthermore, pre-intervention and post-intervention relevant and irrelevant links in gravity concept in the male students' *PFnets* yielded a non-significant interaction between both factors, $F(1, 16) = 1.65; p = 0.22$. Main effects analyses indicated that the presence of misconceptions around gravity concept decreased because of the increase in relevant links and decrease in irrelevant links in gravity concept, $F(1, 16) = 123.33; p = 0.00$. Time factor, on the other hand, exhibited equal change during the pre-intervention and post-intervention, $F(1, 16) = 0.63; p = 0.44$, *ns.* Moreover, the pre-intervention and post-intervention relevant and irrelevant links in gravity concept in the female students' *PFnets* also yielded a non-significant interaction between both factors, $F(1, 6) = 1.00; p = 0.36$. Main effects analyses indicated that the presence of misconceptions around gravity concept decreased because of the increase in relevant links and decrease in irrelevant links in gravity concept, $F(1, 6) = 78.00; p = 0.00$. Time factor (from pre-intervention to post-intervention), on the other hand, exhibited non-significant effect, $F(1, 6) = 1.41; p = 0.28$.

There is a statistically non-significant interaction of the factors of time and links for mass and gravity concepts for both the male and female students separately. Further, there is also non-significant main effect of time on mass and gravity concepts for both the male and female students separately. From this result we may conclude that the male and female students did not improve over time around mass and gravity concepts (hypothesis 3). Therefore, this can be concluded for the male and female students that the presence of misconceptions around mass and gravity did not change because of the intervention. The issue will be further discussed in the chapter 5.

CHAPTER 5: DISCUSSION

Concepts are cognitive entities. A concept, therefore, has an immense network of relations. A concept can be thought of as a theoretical point where meaningful relations converge, and each concept is a crossing point for a multitude of relations. These relations are the fibres from which meaning is constructed. But whenever a concept has restricted meaning or is summarized by a limited number of relations or properties, a simple definition in the form of an analytic proposition can be given. We can artificially restrict the meaning of a concept by formulating definitions. This is often done in science. Still, by and large, concepts have various meanings within different contexts. Therefore, no single, best semantic network exists. Thus, a single concept may mean one thing within one framework and something slightly different within another context. Because of the complexity and pattern of concepts, we should be willing to accept the fact that the acquisition of concepts is a long process which can never be complete. There is no such thing as the final acquisition of a concept. Rather, concept differentiates in every learner's mind. As new relationships are acquired through new knowledge, the respective concepts take on new meaning. Some relations are, of course, more important than others. In short, concepts are never acquired in a finalistic form. Furthermore, certain conceptual relations that are acquired may be inappropriate within a certain context. Such relations are termed as "misconceptions" in this study. A misconception does not exist independently, but is contingent upon a certain existing conceptual framework. As conceptual frameworks change, what was deemed a misconception may no longer be a misconception; conversely, what is a central conceptual relationship in one framework may be a profound misconception within another framework. In the context of this research on misconceptions in the domain of physics, the concept that is scientifically false is considered as a misconception.

In general, an extension of the application of pathfinder network methodology for formative assessment is reported in the present study. As the results demonstrate, analyses of pathfinder networks were undertaken at the subset level for three concepts, *i.e.,* work, mass, and gravity, whereas individualized instructions were given to the students only around the concept of work. The following section summarises the main findings and some suggestions to address misconceptions. Limitations of the study and its main contributions are then considered.

SUMMARY OF THE MAIN FINDINGS

As discussed earlier, pathfinder network methodology can be a useful tool in summative assessment. The majority of studies used pathfinder network to measure overall similarity of students' and instructor's pathfinder networks to measure conceptual knowledge of students, and to develop its utility for summative assessment. These applications see the networks as a unit to calculate network similarity of students and instructor to measure conceptual knowledge for evaluation purposes. In addition to pathfinder networks applications in summative assessment, this study demonstrates the use of pathfinder networks for formative assessment. This offers the possibility of providing students with extremely comprehensive feedback.

Although pathfinder networks have been used in the domain of physics to understand how students and experts organize knowledge about physics, the individual node generated by pathfinder networks have never been used to study misconception or weak conception about a particular concept. That is, network similarity measures only *how much* students' structures differ from instructor's structure; this study went a step forward to indicate specifically *in which* *subsection* structures differ. Therefore, the research demonstrates the potential utility of pathfinder networks for formative assessment.

From this study, we can make several inferences about the conceptual understanding and misconceptions, with a focus on the physics domain of "work, energy, and power" in particular.

Firstly, the students acquired some degree of structural knowledge, or conceptual knowledge about the concepts of work, energy, and power due to the intervention during phase 2 of the study. During phase 2, individualized instructions were given to the students who did not see the relationship among a certain cluster of concepts which were present in the referent network. The degree of similarity in the pre- and post-intervention ratings with the referent network serves as a baseline for assessing possible pre- and post-intervention changes in the pathfinder networks of the students. Clearly, it is important to inform the students that they have certain misconceptions within the context of science. It is unlikely that the misconceptions can be corrected by simply telling the students that concepts A, B, C, and D are all closely related. Presumably, the students need more feedback and exercises on how these concepts are interrelated, and when that feedback was given in an appropriate manner, we observed changes in their network representations. This improvement was evident in the increase of overall similarity of their *PFnets* with the referent network from pre- to post-intervention ratings. When the same analysis was done separately for the male and female students, the overall similarity of the *PFnets* of the male students increased with the referent network and results were similar but not as strong for the female students. Although the overall similarity of the *PFnets* of the female students also increased with the referent network, it showed statistically non-significant results, due to the lesser number of female students in the sample (only 7). Eryilmaz (2002) observed a gender difference in the misconceptions and provided the evidence that male students had fewer misconceptions than female students in force and motion. There are weak evidences that this finding can be extended for this study as the female students did not improve because of the intervention. The intervention probes about the missing links in the students' pathfinder networks also suggest that cognitive structure of the students changed in a way to reduce misconceptions. In the pre-intervention phase, the most related pair of concept was seen to be work and force which was related by 17 students, whereas in the post-intervention phase the most related pair of concept was work and distance which was related by 23 students. The total similarity of work concept with the referent network increased from 0.53 to 0.76. The increase was much smaller for the other concepts about which feedback was not given like mass and gravity concepts. Furthermore, this increase was also statistically non-significant. Also the relationships between related concepts were more frequent than in the pre-intervention phase.

Secondly, consistent with the preceding findings, the work concept in the pathfinder networks of the students changed from pre- to post-intervention phase. Most likely the reason for this change was that individualized instructions were given to each student about the concept of work which stimulated and probably changed some of their misconceptions. Again when this improvement was analyzed separately for the male and female students, it was observed that this improvement can only be definitely concluded for male students and not for female students. Strong evidence (in the form of significant treatments and interaction effects) was provided by the study that individualized instructions, its effect on relevant links in work concept were effective means of reducing the number of misconceptions the students held, and significantly improved the students' similarity of work concept with the referent network. This increase in the similarity index was due to the increase of relevant links in the concept of work in the *PFnets* of the students compared to the referent network. When the same analysis was done separately for the male and female students, strong evidence was provided by the study that individualized instructions, its effect on relevant links in work concept were effective means of reducing the number of misconceptions the male students held. On the other hand, weak evidence (in the form of non-significant treatment and interaction effects) was provided by the study that individualized instructions, its effect on relevant and irrelevant links in work concept were effective means of reducing the number of misconceptions the female students held. A gender difference or lesser number of female students in the sample (only 7) may be the factor.

Thirdly, as the instructions were not given to the students about mass and gravity concepts, therefore, the similarity indices of mass and gravity concepts in the pathfinder networks of the students did not improve significantly from pre- to post-intervention. Although there was a little improvement, that might be because of the practice effect. Again when this improvement was analyzed separately for the male and female students, it was observed that there is no improvement separately in the male and female students, either around the concept of mass or gravity. Strong evidence (in the form of non-significant treatments and interaction effects) was provided by the study that individualized instructions, its effect on relevant and irrelevant links in mass and gravity concepts did not reduce the number of misconceptions the students held, and did not improve the students' similarity of mass or gravity concepts with the referent network. When the same analysis was done separately for the male and female students, strong evidence was provided by the study that individualized instructions, its effect on relevant and irrelevant links in mass and gravity concepts did not reduce the number of misconceptions the male or female students held.

PROCEDURAL DESCRIPTION TO ADDRESS MISCONCEPTIONS

The concepts of "work, energy, and power" are taught in the schools of Ontario at grade 7 level. If the students have misconceptions about these concepts even in grade 11, then one of the findings from this study is that many students retain their misconceptions from one grade to another as they move through school. Hence, we may argue that conventional classroom instructions do not adequately address such misconceptions.

Understanding misconceptions is the most crucial step for improving classroom instructions. Misconceptions exist because students make their own sense of classroom instructions that they receive and they can be addressed by teaching that pays attention to them. Graeber and Johnson (1991) commented,

> It is helpful for teachers to know that misconceptions and buggy errors do exist, that errors resulting from misconceptions or systematic errors do not signal recalcitrance, ignorance, or the inability to learn; how such errors and misconceptions and the faulty reasoning they frequently signal can be exposed; that simple telling does not eradicate students' misconceptions or bugs and that there are instructional techniques that seem promising in helping students overcome or control the influence of misconceptions and systematic errors (p. 1-2).

An informal description of a concept is useful because it specifies the essential meaning of a concept without undue precision or excessive details. By focusing the attention selectively on a few salient features, an informal description can help in relating a concept to more familiar knowledge and in retrieving the concept in complex situations. Indeed, such informal descriptions can be very useful in facilitating problem-solving tasks (Larkin & Reif, 1979).

For example, the work done by the force on a particle may be described by the statement such as "work done is the product of the magnitude of the force and the distance through which the particle moves". Such statements are rather vague, but they make quite clear what essential quantities are interrelated by the term "work" and when this term might be relevant. The descriptions of a concept are only declarative; that is, the term is expressed in the form of a statement. An alternative way of specifying a concept can be by means of a step-by-step procedure specifying how to identify the concept in relation to the other concepts. Such a procedure provides the most explicit and detailed description of a concept. It also has scientific importance as a comprehensive definition, which specifies what the teachers actually *do* to decide whether a concept is properly identified.

These comments can be exemplified by the following detailed description of the concept "work": (1) Consider a specified particle. (2) Consider the mass m of this particle. (3) At some specified time t_1, consider that the particle is at rest with zero velocity, *i.e.,* $v_1 = 0$. (4) Consider some adjacent time t_2 and consider the velocity of the particle at this time. (5) Find the time change $\Delta t = t_2 - t_1$ by subtracting the old time t_1 from the new time t_2. (6) Find the velocity change $\Delta v = v_2 - v_1$ by subtracting vectorially the old velocity v_1 from the new velocity v_2. (7) Calculate the ratio $\Delta v/\Delta t$ to get acceleration a. (8) Multiply this acceleration a with mass m of the particle to get force F. (9) Measure distance d through which the particle moved. (10) Multiply this distance d with the force F. (11) Identify the resulting product as the concept of interest and name it "work done W by the force F on the particle".

This detailed description makes sufficiently clear the many complexities involved in the definition of the concept of "work", the complexities which are largely hidden in the formal definition $W = \vec{F}.\vec{d}$. Indeed, the distinction between a detailed description and formal description adopted in the classroom may be strikingly apparent in practice. For example, when students are asked a question: "Does the work done in raising a box onto a platform depend on how fast it is raised?", many students may say that it does not, because work depends upon force and displacement. Most of them may continue to make this claim, even when they are specifically asked to use the definition of work, written out as $W = \vec{F} . \vec{d}$. But if you ask these students to follow the steps of the detailed procedure specifying the work, they may change their minds and realize that the work done depends on how fast an object is raised.

WHERE THESE MISCONCEPTIONS COME FROM? AN ANALYSIS

Misconceptions in physics may arise for a variety of sources. In the context of the unit on “work, energy, and power”, the following explanations are significant:

1. The concept of work is often regarded as a process that always integrates conceptually with the prior knowledge. While a visual representation of the concept of work plays an important role in understanding this concept, at some time, higher-level knowledge about the concept and its meaning has to be integrated to the prior knowledge of the student to achieve comprehension. If the visual representation of the concepts of work, energy or power and prior knowledge are not compatible, the integration, and hence its comprehension may fail. This type of experiences were observed when the participants were told that work and time are not conceptually strongly related and some questions were asked to the students, but students faced some difficulty in understanding that there is not a strong relation in the two concepts. Data collected from the participants verify that the relation of work and time was the most common misconception among the students. Moreover, if a student lacks certain conceptual information, he/she may misinterpret the concept. Furthermore, such perception may even give birth to a new misconception.
2. Another explanation for misconceptions in the field may come from misapplication of these concepts or erroneous transfer of conceptual knowledge of other concepts. Novick and Hmelo (1994) have shown that problem-solvers can transfer conceptual knowledge between

problems, which may not be related. Analogously, the students may apply rules from other concepts to the concepts of work, energy, and power. The correct interpretation of the concepts of work, energy, and power requires correct identification of application of the concepts and their interpretation. In the absence of relevant interpretation knowledge, the transfer of known interpretation rules from visually similar representations might be tempting for a student and, in consequence, lead to misconceptions.

3. Finally, the concepts of work, energy and power can represent information from a variety of different domains, for example from scalar and vector, from heat, from Newton's laws of motion. Pathfinder networks visualise only certain aspects of a domain which is usually richer but the domain may contain additional relations with other concepts. Consider the concept of heat which is preferred to both energy and scalar concepts in the referent network shown in Figure 3.1(*a*). It is tempting to (wrongly) regard energy and scalar as 'equal' in some sense; since they are drawn at the same horizontal level. In this context, the misconception that respective concepts are 'equal' may arise. The labels of a pathfinder network node can convey additional information that depends specifically on the context and are different in different context. Researchers like Stern, Aprea, and Ebner (2003) have shown the context dependency of the concepts in investigation using expert's ratings.

PARTICIPANTS' COMMENTS

At the end of the third phase, some students and the class teacher gave their comments. The students' comments indicate considerable motivation for this kind of research:

> This kind of exercise and the way to testing is better because it really checks the conceptual understanding and you have to really look deep into the terms. It makes one think hard to get a logically correct relationship. After getting feedback in the form of exercises, I realized that I was not in fact correct in my initial explanation … helped in understanding my misconceptions and it seems that I am confident in my new ideas. (student 13)

> Questions like scalar versus vector are difficult to understand. I like that, even if I do not always get the most suitable answer for my reply. (student 5)
>
> Exercises were wonderful, they gave some idea of conceptual understanding. (student 19)
>
> Through this testing you get real meaning of the terms, and their understanding … I think that by teaching understanding, teacher give students the tools to be good problem solvers and to think conceptually as opposed to just memorizing formulas and solving problems. (student 2)
>
> Students were excited, they consulted their networks with their peers and discussed why they don't have certain links and other do have. (teacher's comments after the second phase)
>
> Students felt difficulty in following the question about the relation of time with the work. They had problems, why an object lifted quickly do the more work and not the same. (teacher's comments after the third phase)

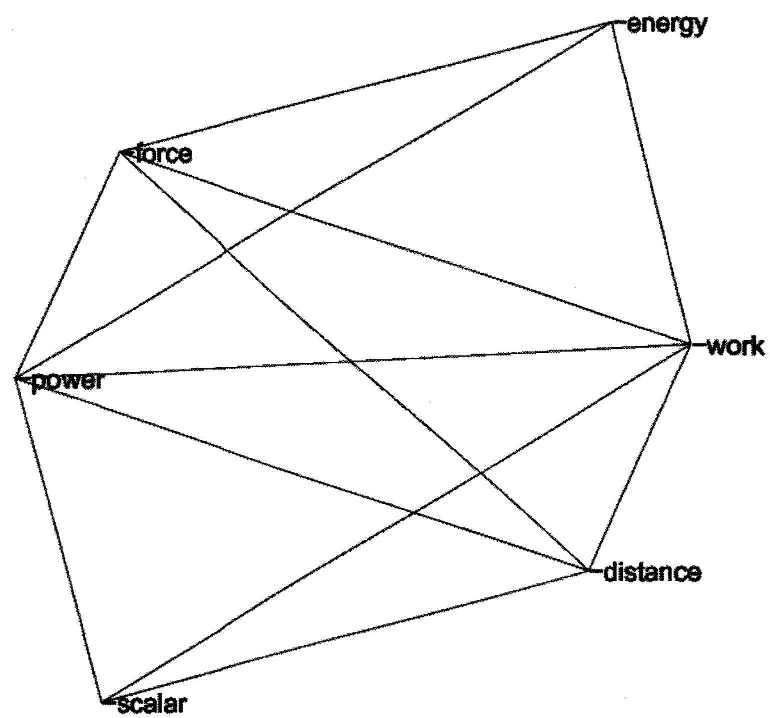
Almost all students expressed the belief that their views had changed. During phase 2 of the experiment, the students not only were engaged in their own feedback, but also had support from their peers in the class. The students assisted their peers in comparing their *PFnets* with others, and related their understanding or misconceptions with others or with the accepted scientific ideas represented in the referent network. This *peer tutoring* may be a factor in changing misconceptions around work concept, which is shown by the results of this study. The importance of feedback during the second phase, of considering the views of others, or relating a concept to real-world phenomena as probed by feedback were all seen to be significant in promoting the changing of views.

LIMITATIONS OF THE STUDY

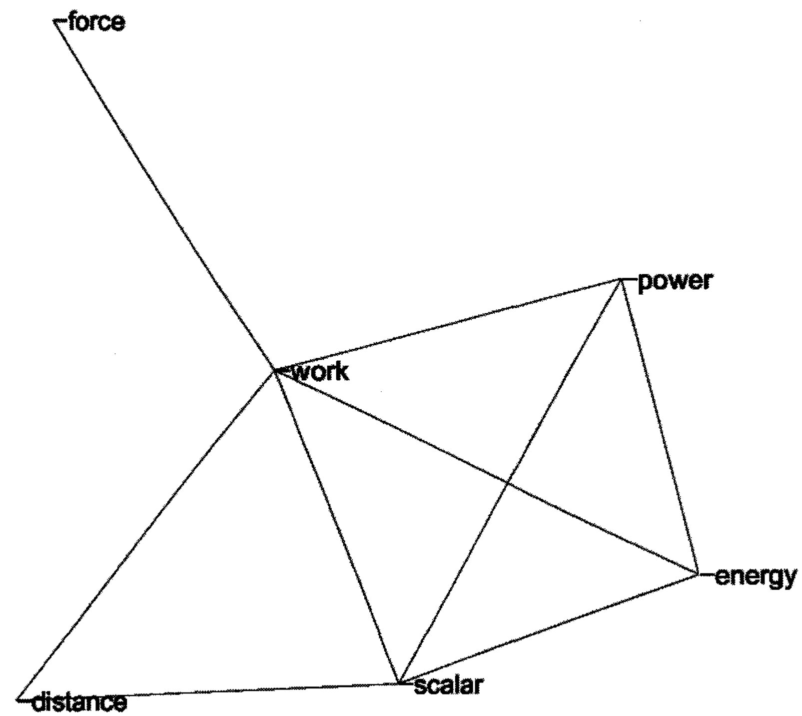
Even though vigorous criteria for data analysis strengthens the quality of the study and limits concerns about validity issues, the study, like every other individual study, has certain limitations. The concepts chosen to represent "work, energy, and power" were based on the opinion of the physics instructor of the high school who was teaching the participant students. Different instructors or experts outside the academic setting of the school may choose different concepts, which could produce different findings. The participant high school physics instructor is teaching students with a variety of cultural and ethnic backgrounds, whose intellectual levels, capacities, and interests are diverse. To manage such a situation, instructors generally give up personal views of physics, at least partially, and try to make some meaning that physics may have for their students. The lack of consideration in teaching the concepts of physics may also be a factor for developing misconceptions among students.

There are a lot of advantages of collecting relatedness ratings using a computer in which a participant enters his ratings directly into a computer. The procedure of collecting relatedness ratings via the paper instrument always adds a factor of difficulty and complexity because the instrument has to be typed, printed, photo-copied, distributed, collected, and manually entered into a computer file prior to data analysis. Although circumstance of this study necessitated the use of paper instrument, participants entering their ratings directly into a computer would have saved time and reduced the complexity.

Another limitation of the method used to calculate similarity index of work concept lies in the technique to calculate this index. For example, the work concepts of the pathfinder networks of the student-23 and student-24 are shown in Figure 5.1(*a, b*). The similarity index for both the students was calculated as 1, because both the students' work concept contains all the links as the referent network has. Under this condition both the student-23 and student-24 would have the identical knowledge about the concept of work. But these two students see the concept of work and the related concepts around it quite differently and we can expect that these two students would make different types of error when writing a test about the concept of work. However, to overcome this disparity, diagnosis can be done at individual link level of a pathfinder network.



(a) Student-23's work concept



(b) Student-24's work concept

Figure 5.1: Two different work concepts with same similarity index

Research by Johnson and Goldsmith (1992) found that making rapid relatedness judgments on the basis of participants' initial intuitions may result in more reliable and valid ratings than allowing unlimited time. In this study, the participants entered their relatedness ratings on paper and were therefore able to change their responses before handing over the paper. Using direct entry into computer would have nullified the students' opportunity to change their ratings once entered.

One of the weaknesses of this method is that it is quite tedious and is useful for a limited set of concepts. The number of pair-wise comparisons increases exponentially with each concept added to the list. So, for example, a list of 11 concepts, as used in this study, results in 55 pair-wise comparisons, but a list of 20 concepts results in 190 pair-wise comparisons. Such a big list would require more than one hour to answer for students. Students can become fatigued or bored with too many ratings. The instructors or researchers, therefore, choose a limited number of concepts to keep the rating task manageable. However, Goldsmith, Johnson and Acton (1991, p. 94) argue that "the decrease in predictive validity with smaller sample sizes is a fairly linear function" and is shown by the graph plotted in Figure 5.2. Therefore, it seems reasonable to include *only* the important concepts in the list. The weaknesses of the pathfinder associative network also include its computational complexity with the increase of the number of nodes. The *PFnet* generation algorithm requires large intermediate matrices to generate the final result. They may require a large amount of computer memory to support the generation of these matrices.

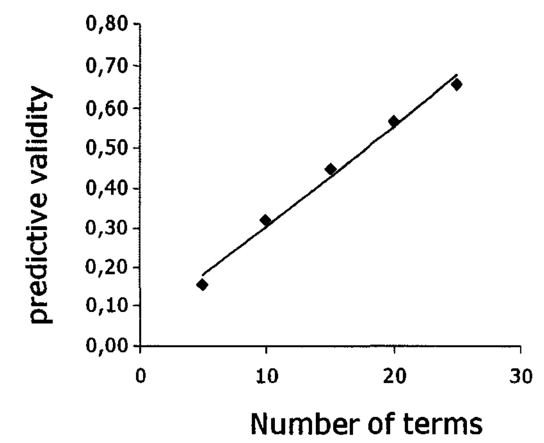


Figure 5.2: Graph between mean predictive validity and number of terms used in sample

MAIN CONTRIBUTIONS OF THE STUDY

Unlike textual description, pathfinder network provides a visual way to describe the knowledge structure of a student. They often provide a clear measure of the student's understanding and highlights the student's misconceptions (Clariana, Koul, & Salehi, 2006, p.321). Pathfinder network methodology, as described in this study, requires the students to take the initiative for their own learning by actively engaging in the process of abstracting ideas and discerning their relationships.Therefore, graphic display of raw or transformed data helps the analyst to explore and to identify the underlying information.

The pathfinder network technique is very efficient and effective for the display of complex relationships among concepts in a particular domain. They have been suggested as an alternative to MDS, providing "a more accurate representation of local data relationships" (Schvaneveldt, 1990, p. 3) and a more appropriate metric when the data are not ratio-scaled (Schvaneveldt, 1990). A number of cognitive scientists have compared *PFnets* with other scaling techniques and found that they provide a useful tool for revealing conceptual structure and for correctly classifying experts and novices (Cooke, Durso, & Schvaneveldt, 1986; Goldsmith & Johnson, 1990; Schvaneveldt, 1990; Trumpower & Goldsmith, 2004). Therefore, by conceptualizing the mental models of students through pathfinder networks, the study highlighted common understandings and misconceptions among the students in the physics domain of "work, energy, and power". The study also went a step forward to indicate specifically *in which subsection* the students' pathfinder networks differ. Therefore, the research demonstrates the potential utility of pathfinder networks for formative assessment. The subset of networks thus generated provided insights needed to identify partially-understood and misunderstood concepts by the students at a single concept level.

The assessment of structural knowledge is not widely used to assess students' learning in schools, because of the lack of research in this area or perhaps the procedure is not currently automated. The findings of this study show that the pathfinder network methodology may be a useful way to understand the conceptual understanding of a student even at sublevel of the structure. Although more research is needed to implement the methodology in a comprehensive form, instructors may consider this methodology as an additional technique to assess the performance of their students for individualized feedback. Future research could be expanded by examining other areas of knowledge. Another extension of this research is to collect data at various points during the whole academic year to track students' progress and to compare their changing conceptualizations, through their knowledge structures, to those of experts.

The pathfinder network methodology can offer a practical tool to represent and evaluate structural knowledge. The quality of an individual's underlying structural knowledge is an indicator of his or her progressive skill acquisition and is positively related to problem solving ability in that domain (Azzarello, 2003; Jonassen & Tessmer, 1997). Although this evaluation was dependent upon the epistemological research paradigm adopted, as a methodology, pathfinder networks can be used in both qualitative and quantitative venues. Qualitative analysis involves visual inspection of the network to see the differences or similarities between two or more networks. This type of analysis instantly reveals misconceptions or differences among knowledge structures of the participants. Furthermore, a pathfinder network may contain one or more cluster(s). Qualitative cluster analysis may give some additional information about the conceptual understanding of an individual or of a group. As such, pathfinder network methodology supports diversity in application as well as methodology and is able to support a broad range of investigations and research paradigms.

This research provides some information about the use of scaling techniques around a particular node in the network which will enable researchers to address structural issues regarding memory organization. Consequently, such enhancements combined with pathfinder will be better suited for any research in the future. Another future incentive of this research is to establish an automatic system for scoring pathfinder networks (Clariana, Koul, & Salehi, 2006). The automatically derived pathfinder networks will be a relatively low-cost and easy to use system. Ongoing research is directed towards expanding this methodology to include other techniques as well as towards validating various aspects of the methodology.

Pathfinder has strength in the evaluation of a kind of knowledge that is essential for cognitive skill development in a classroom. Therefore, instructors may find the examination of students' *PFnets* at a subset level to be more suitable in the formative assessment, as a means to diagnose progress towards development of structural knowledge similar to an expert. This study shows that structural knowledge can be refined through individualized instructions, therefore, pathfinder may also be useful in evaluating the effectiveness of instructional strategies designed specifically to promote structural knowledge development (Azzarello, 2007). Information about common misconceptions among students can also assist curriculum developers and textbook writers in explaining and elaborating particular materials to challenge students' existing misconceptions, and giving them new formulations for more advanced knowledge.

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APPENDIX A: ISSUE AND PROCEDURAL SUBQUESTIONS FOR THE PROPOSED RESEARCH

Issue Subquestions

1. What are the major techniques used by the physics instructors for teaching?
2. How do instructors see the subject or concepts of physics (easy, hard, interesting, etc.)?
3. What is the attitude of physics instructors toward students?
4. What is the meaning of help to instructors?
5. How do the students from different cultural background learn physics?

Procedural Subquestions

1. What is the meaning of structural knowledge to students?
2. What is the difference between researcher's and instructor's approach of possessing structural knowledge in the domain of physics?
3. How does society see the concepts of physics?
4. What is the attitude and approach of students toward physics after learning procedural knowledge?
5. What are the underlying factors that distinguish declarative knowledge from structural knowledge?

APPENDIX B: RECRUITMENT TEXT FOR THE STUDENTS

My name is Gul Shahzad Sarwar and I am a M.A. (Education) candidate at the Faculty of Education, University of Ottawa. I am conducting research in the area of cognitive psychology under the supervision of Dr. David Trumpower.

I am looking for volunteers to participate in a research project. I need about 25 students taking a credit course in physics at grade 12 to participate in an experiment in which you will use a rating scale for pair-wise comparison of concepts in the domain of physics. The purpose of the experiment is to study both understanding and misconceptions in the domain of physics.

If you are willing to participate, there will be three sessions of the study that will take approximately 30 minutes each to complete. During the first session, students will complete the pair-wise comparison rating task, during the second session, they will be given individualized take-home instructional packets to complete, and during the third session they will complete the pair-wise comparison task a second time. The study will be conducted during school hours. Without any penalty, you may withdraw from this project at any time, can refuse to participate in any activity. At the same time, however, your involvement in this study may enable you to reflect on your own understanding.

If you have any questions about this research now or at any time throughout the study, please email me at If you are willing to participate, please fill out the assent form and sign it and take home a copy for your parents/guardians to read and sign. Please return both your and your parents' or guardians' signed forms to me next week.

Gul Shahzad Sarwar
Faculty of Education
University of Ottawa
Phone:

Dr. David Trumpower
Thesis Supervisor
University of Ottawa
Phone: 613-562-5800x4117

APPENDIX C: RECRUITMENT TEXT FOR THE TEACHER

My name is Gul Shahzad Sarwar and I am a M.A. (Education) candidate at the Faculty of Education, University of Ottawa. I am conducting research in the area of cognitive psychology under the supervision of Dr. David Trumpower. The purpose of this study is to represent the knowledge structure of participants by using the pathfinder networks software. Pathfinder networks provide the basis of a conceptual framework to address three practical issues: (1) identifying the nature and type of misconceptions among students, (2) determining if differences in knowledge structure of different students can help to explain differences in students' performance, and (3) using misconceptions identified by knowledge structures to create individualized instruction.

I am looking for a volunteer physics instructor teaching at grade 12 to participate in this research project. In this experiment you will use a rating scale for pair-wise comparison of concepts in the domain of physics. The purpose of the experiment is to highlight students' understanding and misconceptions in the domain of physics, and to create individualized instruction based on that knowledge.

If you are willing to participate, there will be three sessions of the study that will take approximately 30 minutes each to complete. During the first session, students will complete the pair-wise comparison rating task, during the second session, they will be given individualized take-home instructional packets to complete, and during the third session they will complete the pair-wise comparison task a second time. The study will be conducted during school hours. I need your permission to collect data from your students and to be present as an observer during the whole process of data collection. I also ask that you actively participate during the first session by completing the pair-wise comparison task. Please note that we are not interested in assessing your physics knowledge. Rather, we will use your knowledge structure as the standard against which the students' knowledge structures will be compared.

Without any penalty, you may withdraw from this project at any time and may refuse to participate in any activity. At the same time, however, your involvement in this study may enable your students to reflect on their understanding.

If you have any questions about this research now or at any time throughout the study, please email me at To indicate your decision to participate in this study, please fill out the consent form and sign it.

Gul Shahzad Sarwar
Faculty of Education
University of Ottawa
Phone:

Dr. David Trumpower
Thesis Supervisor
University of Ottawa
Phone: 613-562-5800×4117

APPENDIX D: LETTER OF INFORMATION

STRUCTURAL ASSESSMENT OF KNOWLEDGE FOR MISCONCEPTIONS IN THE DOMAIN OF PHYSICS

The purpose of this research study, which is a part of the requirements for my M.A. (Education), is to assess students' misconceptions in the domain of physics. Many students express difficulties in learning physics concepts because of these misconceptions. However, traditional approaches of assessment such as multiple-choice questions and word problems often fail to identify misconceptions. The motivation for this study is to examine a different approach for assessing students' understanding of basic physics concepts. This approach examines mental representations of the relationship among concepts, also called structural knowledge. This study may benefit teachers' understanding of students' knowledge structures and thinking, which will lead to using improved pedagogy and instructional strategies.

The study will be conducted during class time in school hours. There are three steps of the study that will take approximately 30 minutes each to be completed.

1. The students and their instructor will be asked to rate the relatedness of pairs of physics concepts on a scale from 1 to 5. Through these ratings the study will assess the knowledge structures of students and their instructor using *Pathfinder* software (an algorithm that results in a kind of concept map). The students' knowledge structures will be compared to the instructor's knowledge structure in order to identity students' understanding and misconceptions.

2. Individualized instructions and exercises about concepts of physics will be given to the students based on their understanding and misconceptions identified in step 1.
3. The students will be asked again to rate the relatedness of the same concepts of physics. The study will analyze the change in the knowledge structures of the students around these concepts resulting from the individualized instruction.

The information collected for this study is confidential and protected under the Municipal Freedom of Information and Protection of Privacy Act, 1989. Students' identities will be kept anonymous. Students' name will not appear in the research or any publications or presentations resulting from the research. To ensure confidentiality all data will be stored in a password-protected computer and will be accessible only to me and my thesis supervisor. It will be kept in this manner for five years after the completion of this study and then destroyed.

Students may either withdraw or refuse to participate in an activity at any time without any adverse consequences. The results of the study will not appear in any school records. At the same time, however, students' involvement in this study will help them to reflect on their own understanding.

The University of Ottawa Research Ethics Board, the Ottawa-Carleton Research Advisory Committee, and the principal of the school have approved this research. Any information requests or complaints about the ethical conduct of the project may be addressed to the Protocol Officer for Ethics in Research at the University of Ottawa (613-562-5841 or e-mail at ethics@uottawa.ca) or my thesis supervisor, Dr. David Trumpower (613-562-5800×4117 or email at david.trumpower@uottawa.ca). Dr. David Trumpower is an assistant professor in the Faculty of Education at the University of Ottawa.

If you have any questions about this research now or at any time throughout the study, please email me at   To indicate your decision to participate in this study, please sign the attached consent form and send it back with your child.

Gul Shahzad Sarwar
Faculty of Education
University of Ottawa
Phone:

Dr. David Trumpower
Thesis Supervisor
University of Ottawa
Phone: 613-562-5800×4117

APPENDIX E: ASSENT FORM

STRUCTURAL ASSESSMENT OF KNOWLEDGE FOR MISCONCEPTIONS IN THE DOMAIN OF PHYSICS

Researcher
Gul Shahzad Sarwar
Faculty of Education
University of Ottawa
Phone:

Research Supervisor
Dr. David Trumpower
Thesis Supervisor
University of Ottawa
Phone: 613-562-5800×4117

You are invited to participate in a study that will attempt to assess your understanding and misconceptions (if any exist!) in the domain of physics.

I am interested in identifying partially-understood and misunderstood concepts by students in the domain of physics. This will help me to prepare individualized lessons intended to clarify misconceptions. After completing the individualized lessons, I will again assess the students' knowledge for a change in their understanding. This will enable me to report changes in the conceptual understanding of physics in the participants.

The information collected for this study is confidential and protected under the Municipal Freedom of Information and Protection of Privacy Act, 1989. Your identity will be kept anonymous. Your name will not appear in the research or any publications or presentations resulting from the research. The results of the study will not appear in any school records. To ensure confidentiality all data will be stored in a password-protected computer and will be accessible only to me and my thesis supervisor. It will be kept in this manner for five years after the completion of this study and then destroyed.

Participation in this study is on voluntary basis. Without any penalty, you may withdraw from this project at any time and can refuse to participate in any activity. At the same time, however, your involvement in this study will help you to reflect on your own understanding.

If you have any questions about this research now or at any time throughout the study, please email me at r call at To indicate your decision to participate in this study, please sign the assent form. Your parent(s) have also been asked to permit your participation in this study.

Student's name ______________________________

Signature:______________________ Date__________

APPENDIX F: CONSENT FORM FOR THE PARENTS

STRUCTURAL ASSESSMENT OF KNOWLEDGE FOR MISCONCEPTIONS IN THE DOMAIN OF PHYSICS

Researcher
Gul Shahzad Sarwar
Faculty of Education
University of Ottawa
Phone:

Research Supervisor
Dr. David Trumpower
Thesis Supervisor
University of Ottawa
Phone: 613-562-5800×4117

Your child is invited to participate in the above mentioned research study conducted by Gul Shahzad Sarwar. The purpose of this research study is to assess students' understanding and misconceptions in the domain of physics.

If you allow your child to participate in this study, your child will attend three sessions of approximately 30 minutes each during the school hours. He or she will be asked to rate the relatedness of some concepts of physics in the form of a questionnaire and then will be given an individualized lesson on a particular concept in the field of physics.

The results of this research may benefit your child by identifying some misconceptions in the domain of physics and may help him or her to reflect on his or her own understanding. Although these are our expectations, we cannot guarantee that your child personally will receive any benefits from this research.

The information collected for this study is confidential and protected under the Municipal Freedom of Information and Protection of Privacy Act, 1989. Students' identities will be kept anonymous. Students' name will not appear in the research or any publications or presentations resulting from the research. The results of the study will not appear in any school records. To ensure confidentiality all data will be stored in a password-protected computer and will be accessible only to me and my thesis supervisor. It will be kept in this manner for five years after the completion of this study and then destroyed. There is no cost to participate in this study, and there is no payment to participate in it.

Your child's participation in this study is voluntary. Your decision whether or not to allow your child to participate will not affect his or her relationship with the teacher(s). If you allow your child to participate in the study, you will be free to withdraw your consent and to discontinue participation at any time without any penalty. If you choose to withdraw, all data gathered from your child until the time of withdrawal will be destroyed immediately.

The University of Ottawa Research Ethics Board, the Ottawa-Carleton Research Advisory Committee, and the principal of your child's school have approved this research. Any information requests or complaints about the ethical conduct of the project may be addressed to the Protocol Officer for Ethics in Research at the University of Ottawa (613-562-5841 or e-mail at ethics@uottawa.ca) or my thesis supervisor, Dr. David Trumpower (613-562-5800×4117 or email at david.trumpower@uottawa.ca). Dr. David Trumpower is an assistant professor in the Faculty of Education at the University of Ottawa.

If you have any questions about this research now or at any time throughout the study, please email me at To indicate your decision for your child's participation in this study, please sign the attached consent form and send it back with your child.

I have read and understood the request for my child to participate in the study of "structural assessment of knowledge for misconceptions in the domain of physics". I have discussed it with my child and ...

☐ I give permission for him/her to participate.

☐ I do not give permission for my child to participate.

Name of Student: (please print)____________________ Date: _______

Name of Parent/Guardian: (please print) _________________________

Signature of Parent/Guardian: ________________________________

APPENDIX G: CONSENT FORM FOR THE TEACHER

STRUCTURAL ASSESSMENT OF KNOWLEDGE FOR MISCONCEPTIONS IN THE DOMAIN OF PHYSICS

Researcher
Gul Shahzad Sarwar
Faculty of Education
University of Ottawa
Phone:

Research Supervisor
Dr. David Trumpower
Thesis Supervisor
University of Ottawa
Phone: 613-562-5800×4117

You are invited to participate in the above mentioned research conducted by Gul Shahzad Sarwar. The purpose of this research is to assess students' understanding and misconceptions in the domain of physics. If you are willing to participate in this study, you will be asked to rate the relatedness of some concepts of physics in the form of a questionnaire.

The results of this research may benefit your students by identifying some misconceptions in the domain of physics and may help them to reflect on their own understanding. Although these are our expectations, we cannot guarantee that every individual student will receive benefits from this research.

The information collected for this study is confidential and protected under the Municipal Freedom of Information and Protection of Privacy Act, 1989. Your identity will be kept anonymous. Your name will not appear in the research or any publications or presentations resulting from the research. The results of the study will not appear in any school records. To ensure confidentiality all data will be stored in a password-protected computer and will be accessible only to me and my thesis supervisor. It will be kept in this manner for five years after the completion of this study and then destroyed. There is no cost to participate in this study, and there is no payment to participate in it.

Your participation in this study is voluntary and if you decide to participate in the study, you will be free to withdraw your consent and to discontinue participation at any time without any penalty. If you choose to withdraw, all data gathered from you until the time of withdrawal will be destroyed immediately.

If I have any questions about the study, you may contact the researcher or his supervisor. If you have any questions regarding the ethical conduct of this study, you may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 159, Ottawa, ON K1N 6N5, Tel.: 613-562-5841, Email: ethics@uottawa.ca

Your signature indicates that you have read and understand the information provided above, that you willingly agree to participate, and that you may withdraw your consent at any time and may discontinue your participation without any penalty.

Teacher's Name: (please print)____________________ Date: _______

Signature of the teacher: ____________________________________

APPENDIX H: SAMPLE QUESTIONNAIRE

Name (please PRINT): ____________________

Gender: ____________________

This is a relational test. In this test you will be asked to rate the relatedness of the terms. The terms can be related in many ways—they can be in the same category, used in a similar way, or even related by time. For example, we would say that "bird" and "nest" were highly related as well as "hurt" and "ambulance", "early" and "morning", and so forth.

Example:

Terms:

Bat
Bird
Blue Jay
Chicken
Nest
Mammal

Each of the terms in this list are broadly related to the categories of vertebrates

Word Pairs and their Possible Ratings:

Nest	Mammal	❶	2	3	4	5
Bat	Blue Jay	1	2	❸	4	5
Chicken	Mammal	❶	2	3	4	5
Bat	Chicken	1	❷	3	4	5
Chicken	Blue Jay	1	2	3	❹	5
Bird	Blue Jay	1	2	3	4	❺

Bubble in "1" if you feel they are less related

Bubble in "5" if you feel they are more related

Although all of the terms are broadly related to vertebrates, certain word-pairs are less/more related than are others.

LIST OF CONCEPTS FOR RATING

Directions: List of eleven concepts to be rated:

1. Distance
2. Energy
3. Force
4. Gravity
5. Heat
6. Mass
7. Power
8. Scalar
9. Time
10. Vector
11. Work

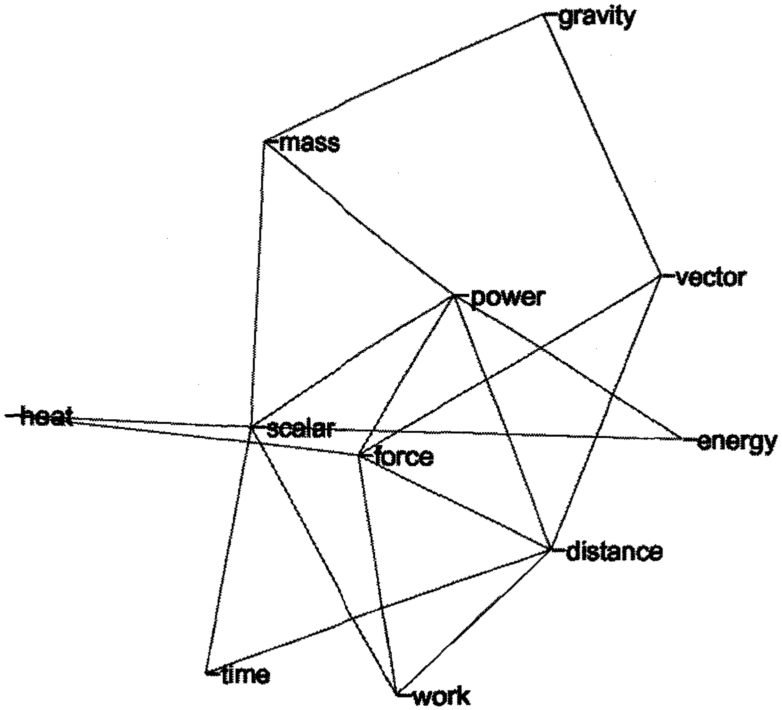
These terms are broadly related to "Work, Energy, and Power". Your task is to look at the pairs of terms and to rate each pair as to how related you think the two items in each pair are to one another. Some pairs of concepts will be more related than others, therefore you should use the entire scale (*i.e.,* select a number from 1 to 5 to indicate how related you think the terms are and don't enter the same rating for *every* pair). Use '1' or '2' for pairs that are less related, and '4' or '5' for pairs that are more related. If you are uncertain about the relatedness of a pair, give it a middle value. Use what you have learned about the terms to rate their relatedness. Once you have selected a rating, circle the corresponding number on your answer sheet.

		Less Related				More Related
Energy	Force	1	2	3	4	5
Time	Vector	1	2	3	4	5
Work	Power	1	2	3	4	5
Gravity	Distance	1	2	3	4	5
Time	Work	1	2	3	4	5
Work	Force	1	2	3	4	5
Gravity	Time	1	2	3	4	5
Distance	Work	1	2	3	4	5
Force	Mass	1	2	3	4	5
Scalar	Work	1	2	3	4	5
Gravity	Heat	1	2	3	4	5
Energy	Scalar	1	2	3	4	5
Heat	Force	1	2	3	4	5
Power	Energy	1	2	3	4	5
Scalar	Power	1	2	3	4	5
Force	Time	1	2	3	4	5
Mass	Energy	1	2	3	4	5
Distance	Power	1	2	3	4	5
Time	Energy	1	2	3	4	5
Power	Time	1	2	3	4	5
Energy	Gravity	1	2	3	4	5
Scalar	Force	1	2	3	4	5
Power	Heat	1	2	3	4	5
Gravity	Power	1	2	3	4	5
Power	Force	1	2	3	4	5
Vector	Power	1	2	3	4	5
Work	Energy	1	2	3	4	5
Mass	Heat	1	2	3	4	5
Heat	Vector	1	2	3	4	5
		Less Related				More Related

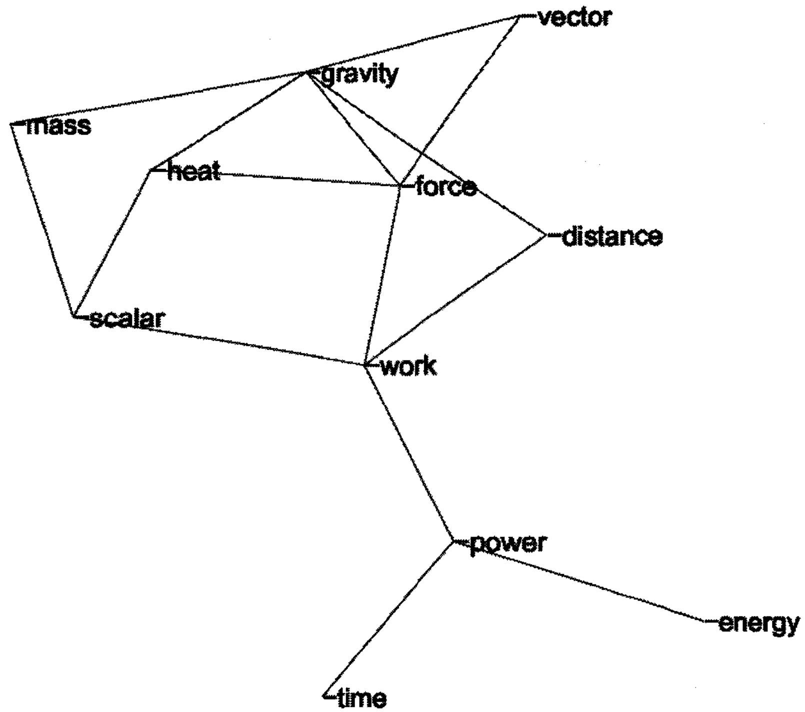
		Less Related				More Related
Time	Scalar	1	2	3	4	5
Force	Gravity	1	2	3	4	5
Heat	Scalar	1	2	3	4	5
Mass	Time	1	2	3	4	5
Energy	Distance	1	2	3	4	5
Scalar	Mass	1	2	3	4	5
Vector	Gravity	1	2	3	4	5
Distance	Time	1	2	3	4	5
Mass	Gravity	1	2	3	4	5
Distance	Mass	1	2	3	4	5
Gravity	Scalar	1	2	3	4	5
Work	Heat	1	2	3	4	5
Force	Vector	1	2	3	4	5
Work	Mass	1	2	3	4	5
Gravity	Work	1	2	3	4	5
Vector	Work	1	2	3	4	5
Distance	Scalar	1	2	3	4	5
Vector	Distance	1	2	3	4	5
Energy	Vector	1	2	3	4	5
Time	Heat	1	2	3	4	5
Scalar	Vector	1	2	3	4	5
Heat	Energy	1	2	3	4	5
Power	Mass	1	2	3	4	5
Heat	Distance	1	2	3	4	5
Vector	Mass	1	2	3	4	5
Force	Distance	1	2	3	4	5
Work	Scalar	1	2	3	4	5
Time	Power	1	2	3	4	5
Heat	Work	1	2	3	4	5
		Less Related				More Related

APPENDIX I: PATHFINDER NETWORKS OF THE PARTICIPANTS

Student-1's Pathfinder network



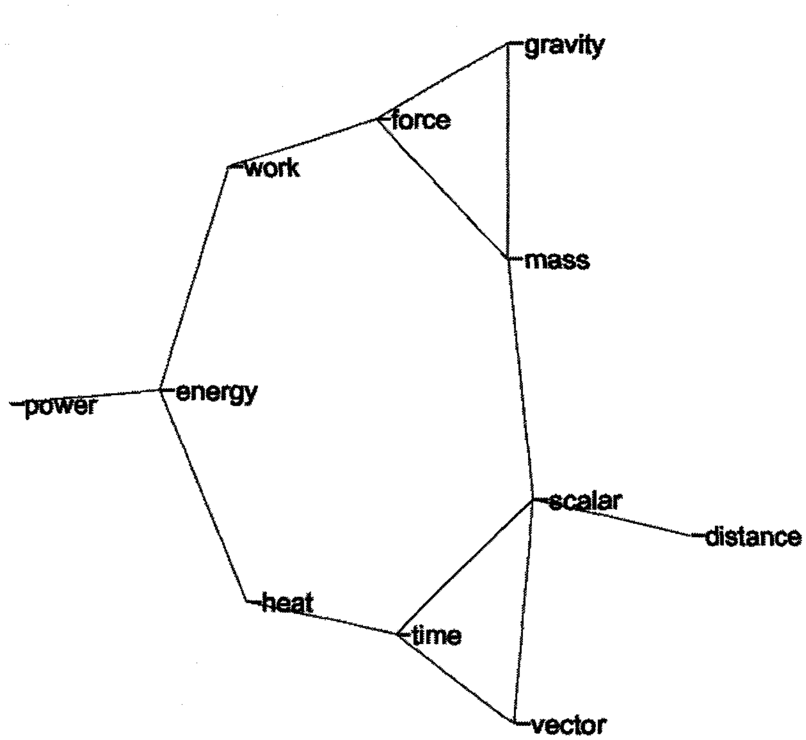
Student's Pathfinder network



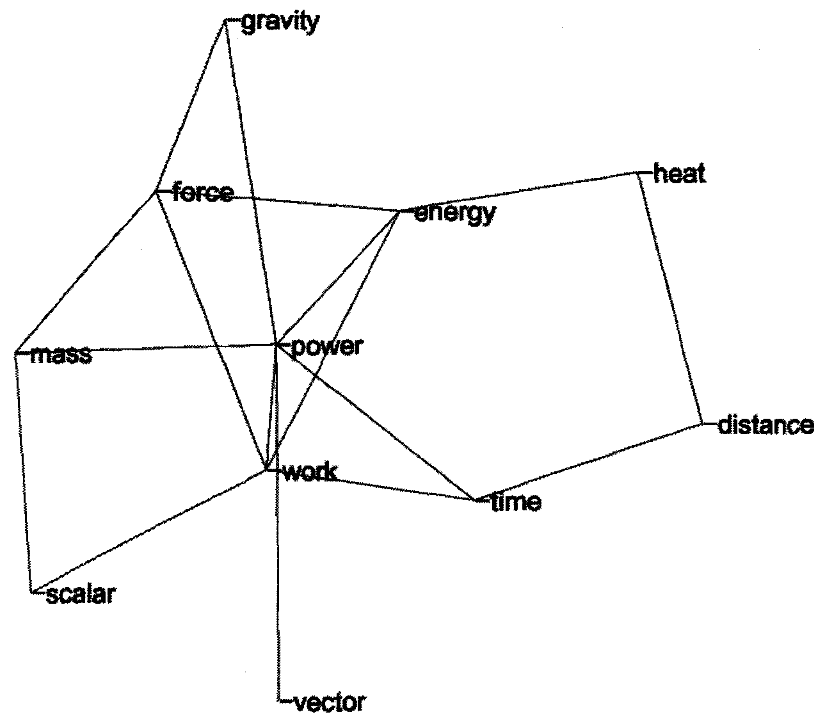
Student's modified Pathfinder network

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance", "force" and "scalar". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power" and "energy". Can you think of ways in which "work" is strongly related to "power" and "energy"?

Student-2's Pathfinder network



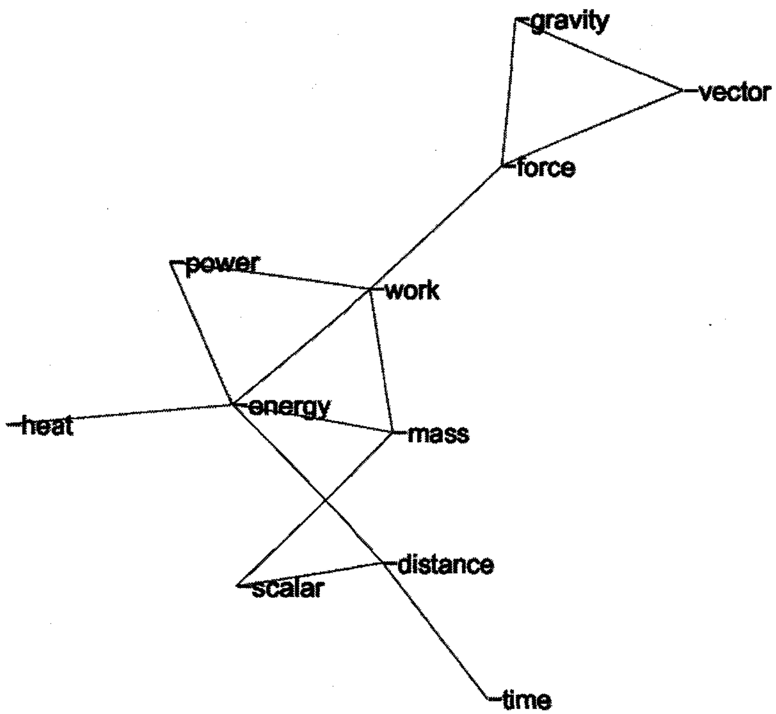
Student's Pathfinder network



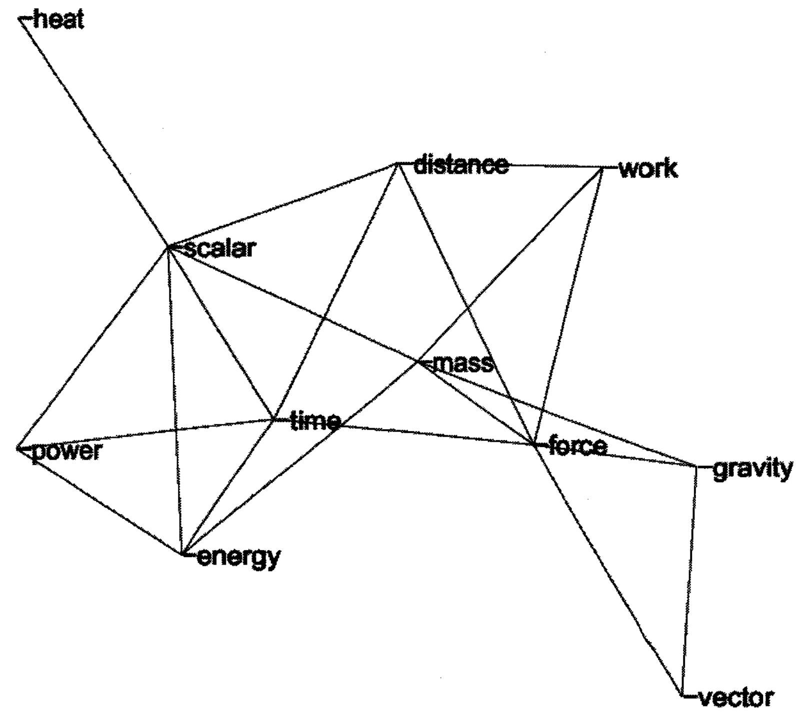
Student's modified Pathfinder network

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "force" and "energy". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power", "distance" and "scalar". Can you think of ways in which "work" is strongly related to "power", "distance" and "scalar"?

Student-3's Pathfinder network



Student's Pathfinder network

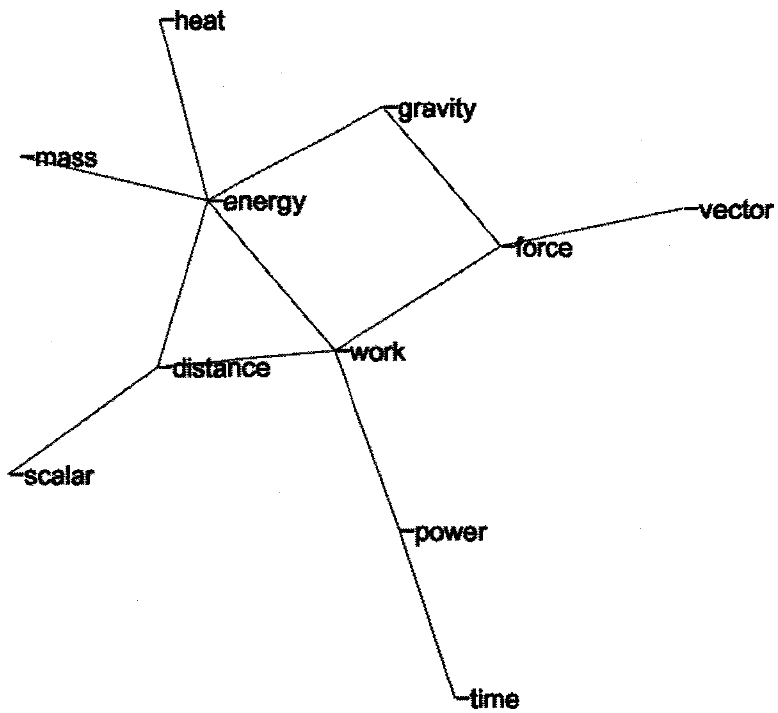


Student's modified Pathfinder network

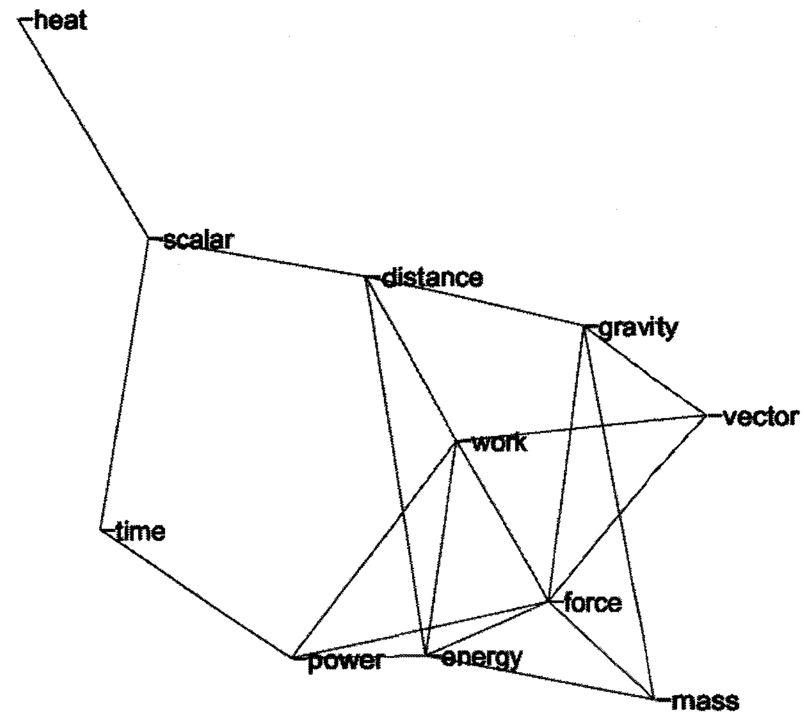
Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "power", "force" and "energy". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "scalar" and "distance". Can you think of ways in which "work" is strongly related to "scalar" and "distance"?

Your ratings also indicate that you see the concepts "work" and "mass" as being relatively strongly related. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which "work" and "mass" are NOT very strongly related?

Student-4's Pathfinder network



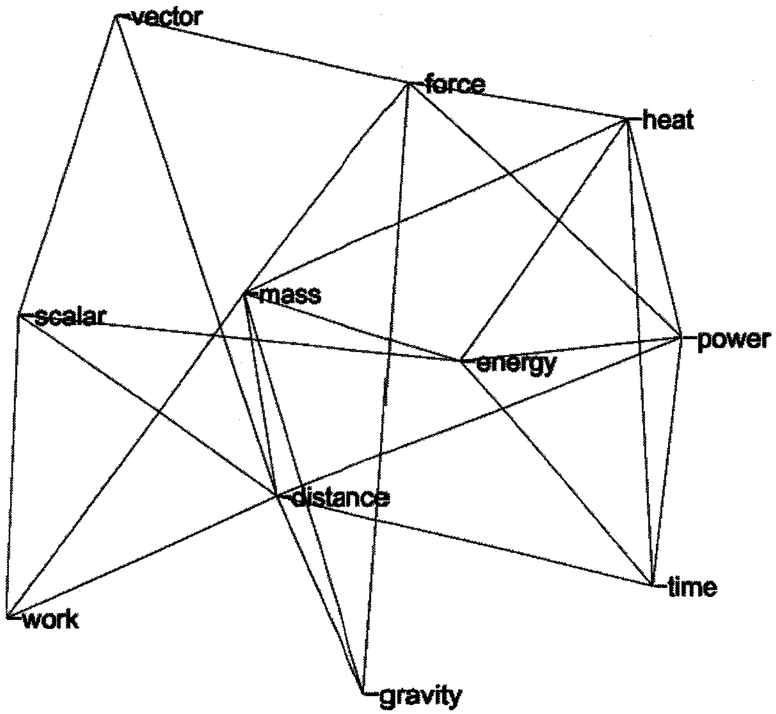
Student's Pathfinder network



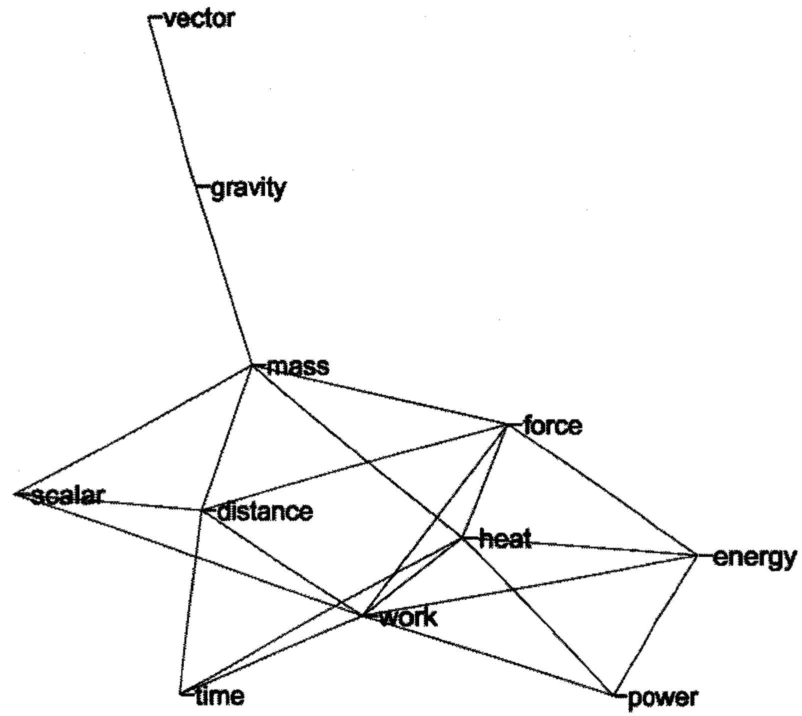
Student's modified Pathfinder network

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance", "force", energy" and "power". Many expert scientists think that the concept of "work" is also strongly related to the concept of "scalar". Can you think of ways in which "work" is strongly related to "scalar"?

Student-5's Pathfinder network



Student's Pathfinder network

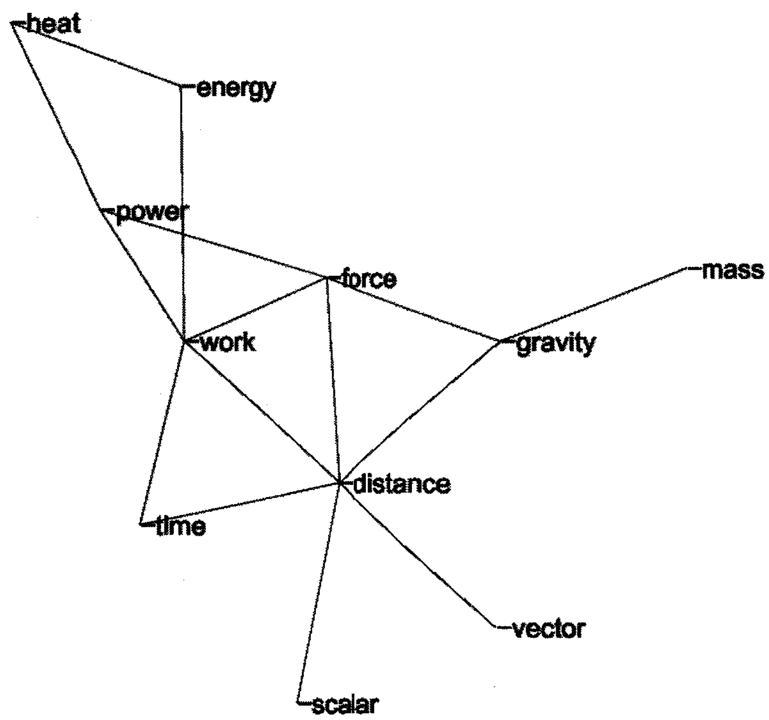


Student's modified Pathfinder network

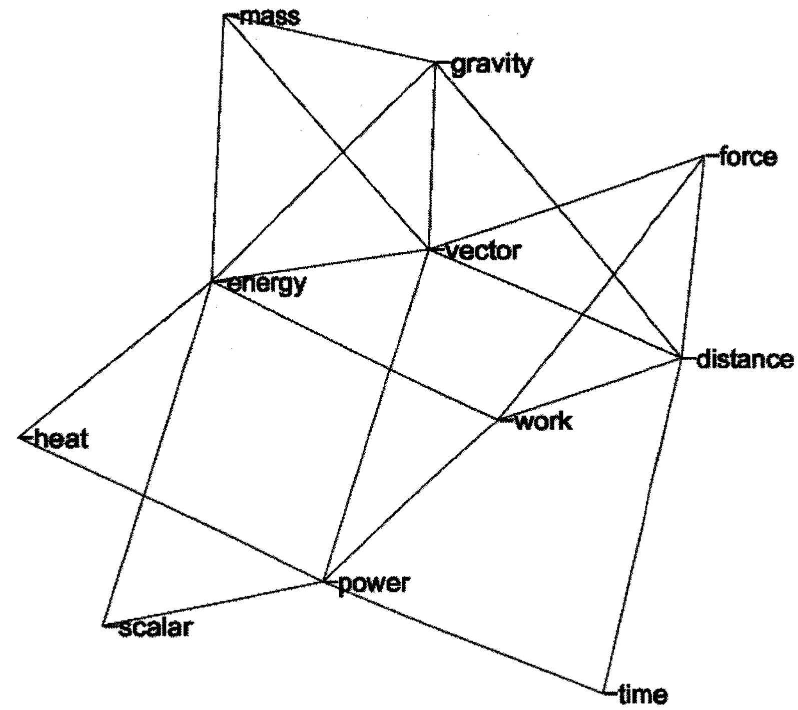
Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance" and "scalar". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power", "force" and "energy". Can you think of ways in which "work" is strongly related to "power", "force" and "energy"?

Your ratings also indicate that you see the concepts "work" and "mass" as being relatively strongly related. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which "work" and "mass" are NOT very strongly related?

Student-6's Pathfinder network



Student's Pathfinder network

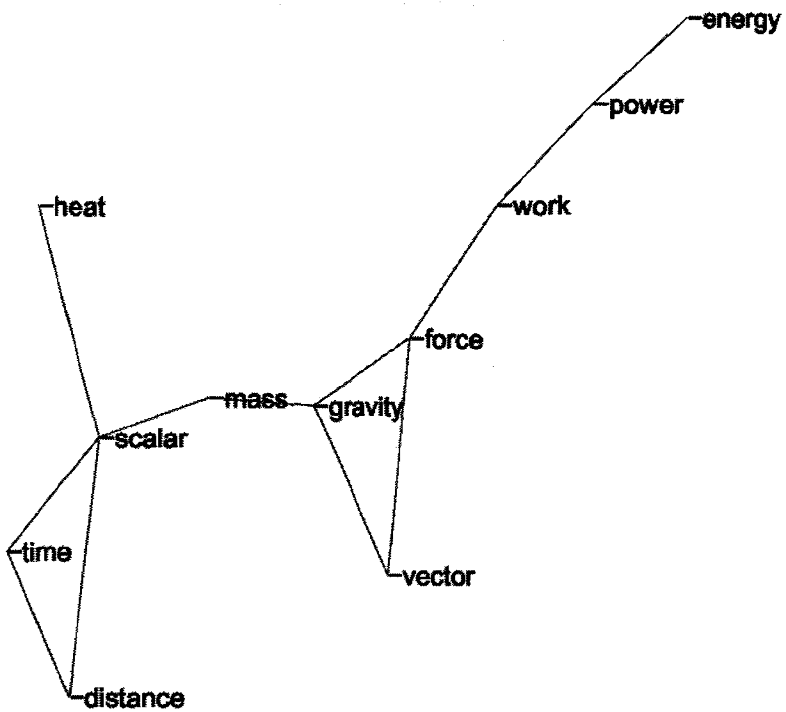


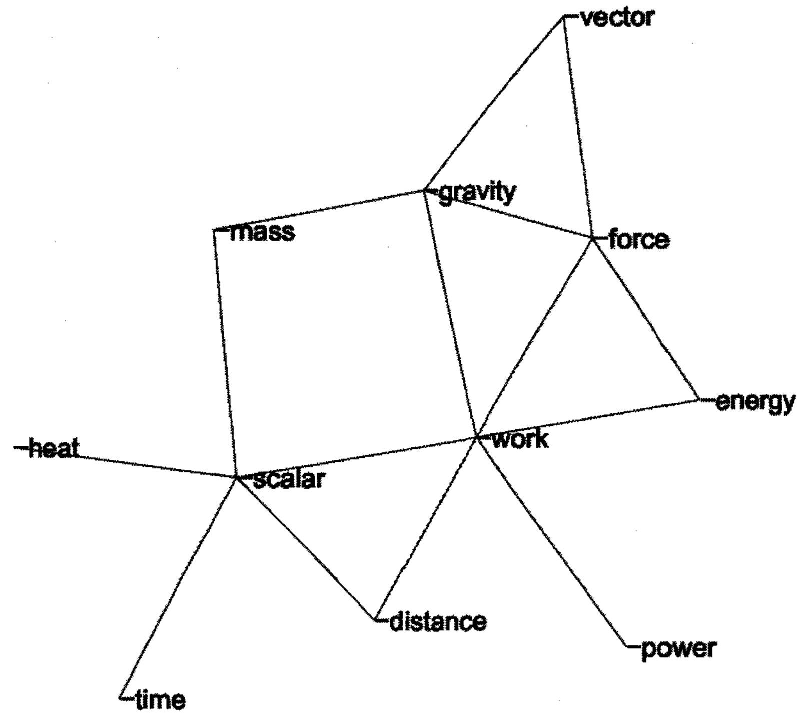
Student's modified Pathfinder network

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance", "power", "force" and "energy". Many expert scientists think that the concept of "work" is also strongly related to the concept of "scalar". Can you think of ways in which "work" is strongly related to "scalar"?

Your ratings also indicate that you see the concepts "work" and "time" as being relatively strongly related. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which "work" and "time" are NOT very strongly related?

Student-7's Pathfinder network

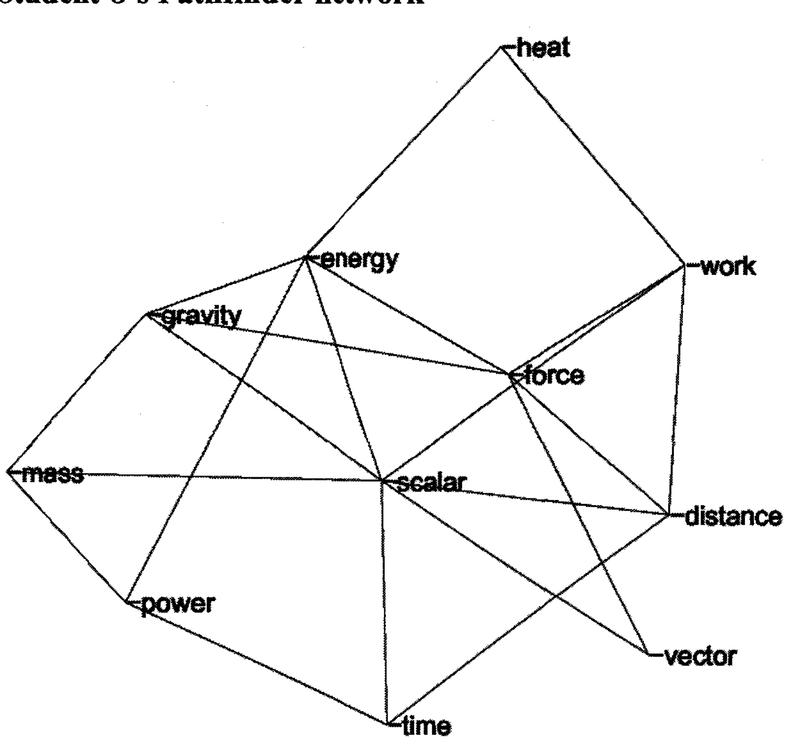




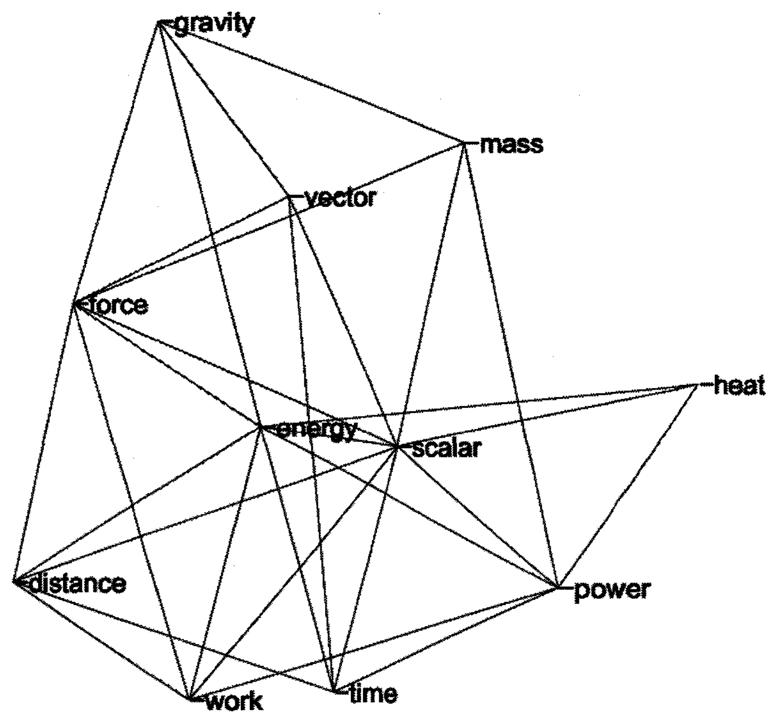
Student's Pathfinder network **Student's modified Pathfinder network**

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "power" and "force". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "distance", "scalar" and "energy". Can you think of ways in which "work" is strongly related to "distance", "scalar" and "energy"?

Student-8's Pathfinder network



Student's Pathfinder network

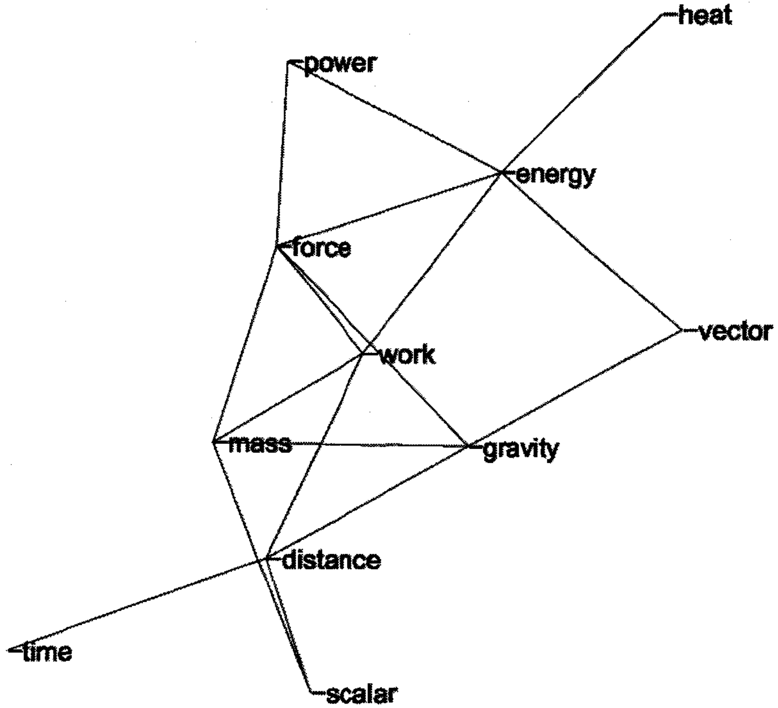


Student's modified Pathfinder network

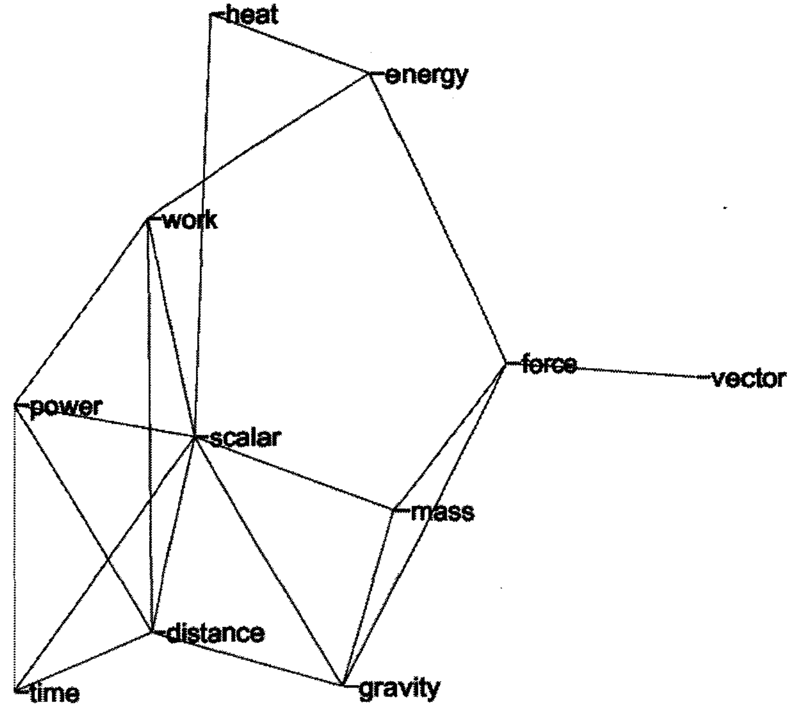
Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance", "force" and "scalar". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power" and "energy". Can you think of ways in which "work" is strongly related to "power" and "energy"?

Your ratings also indicate that you see the concepts "work" and "heat" as being relatively strongly related. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which "work" and "heat" are less related as compared to "work" and "energy"?

Student-9's Pathfinder network



Student's Pathfinder network

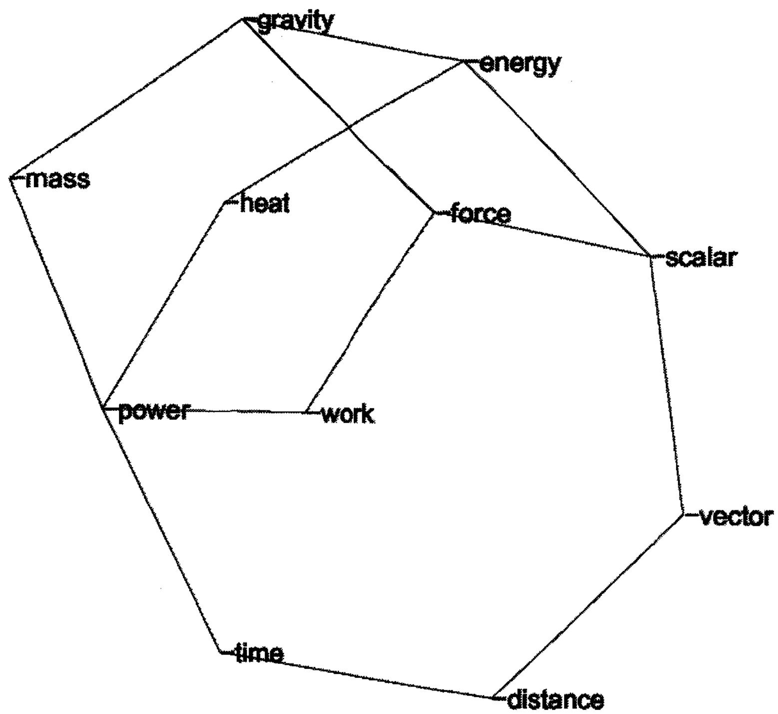


Student's modified Pathfinder network

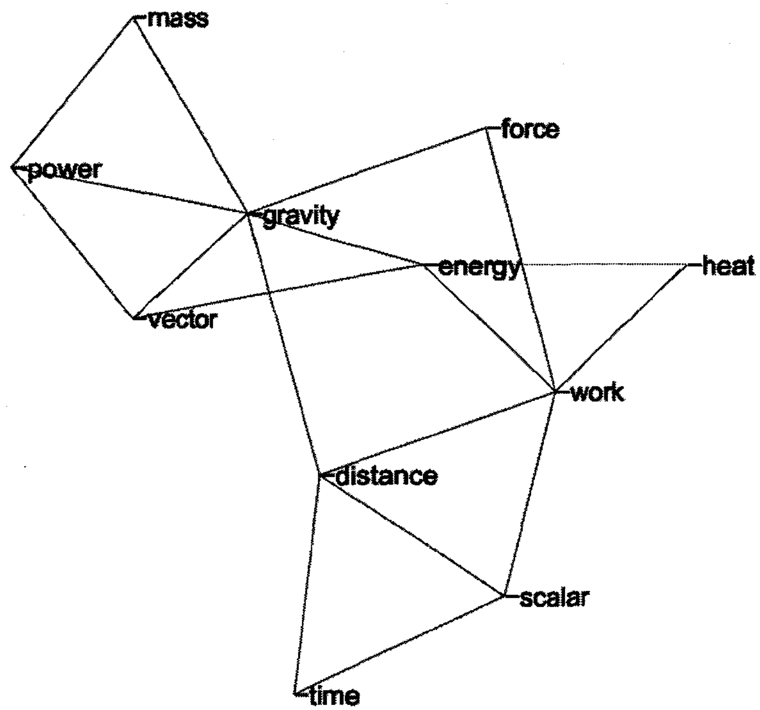
Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance", "force" and "energy". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power" and "scalar". Can you think of ways in which "work" is strongly related to "power" and "scalar"?

Your ratings also indicate that you see the concepts "work" and "mass" as being relatively strongly related. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which "work" and "mass" are NOT very strongly related?

Student-10's Pathfinder network



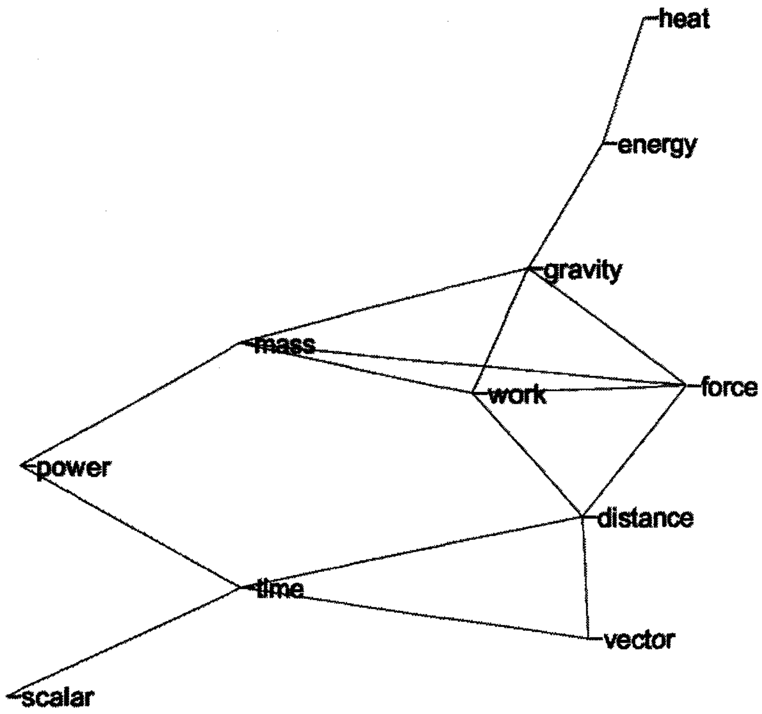
Student's Pathfinder network



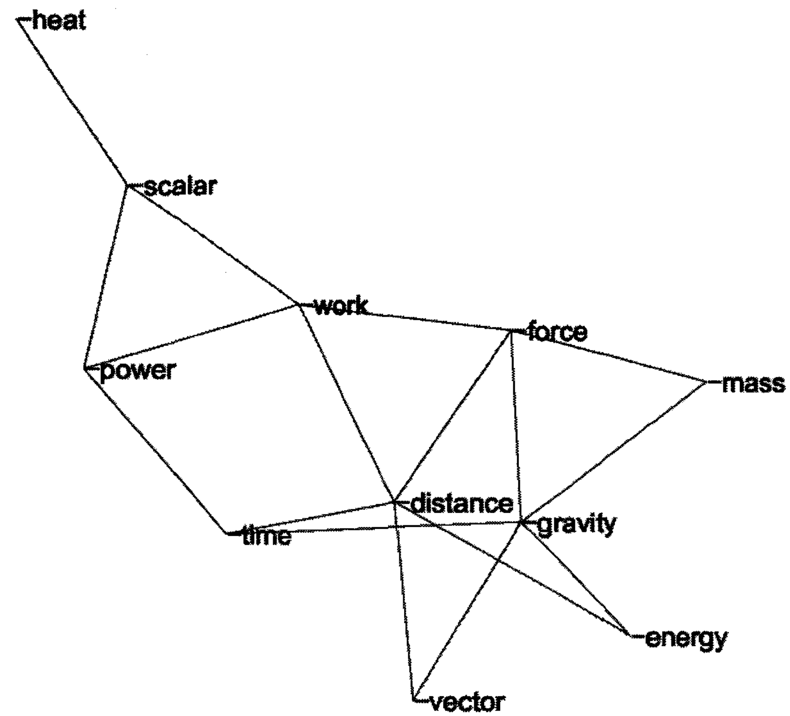
Student's modified Pathfinder network

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "power" and "force". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "distance", "scalar" and "energy". Can you think of ways in which "work" is strongly related to "distance", "scalar" and "energy"?

Student-11's Pathfinder network



Student's Pathfinder network

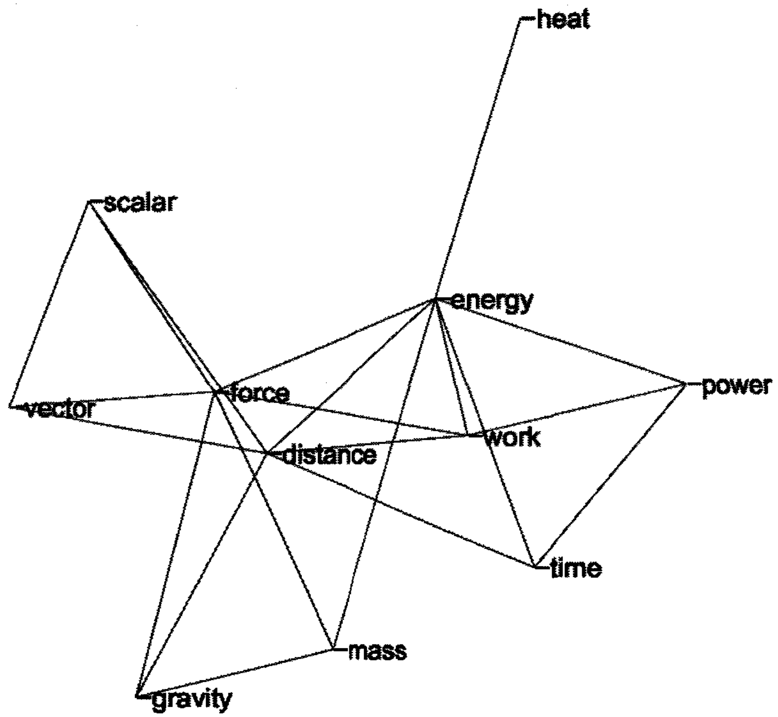


Student's modified Pathfinder network

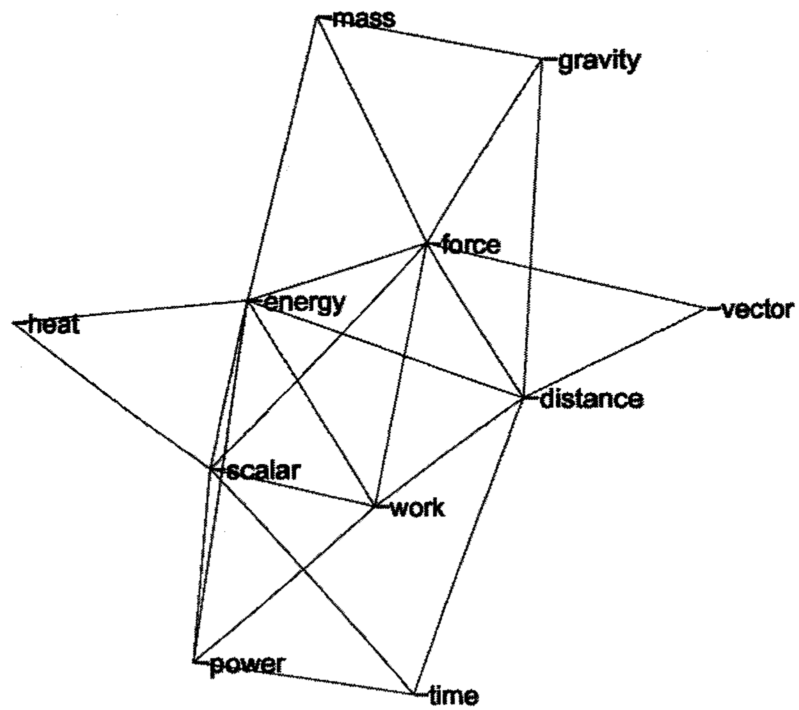
Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance" and "force". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power" , "energy" and "scalar". Can you think of ways in which "work" is strongly related to "power", "energy" and "scalar"?

Your ratings also indicate that you see the concept of "work" as being relatively strongly related to the concepts of "gravity" and "mass". Many expert scientists do not see these concepts as being quite as strongly related to the "work". Can you also think of ways in which "work" is NOT very strongly related to "gravity" and "mass"?

Student-12's Pathfinder network



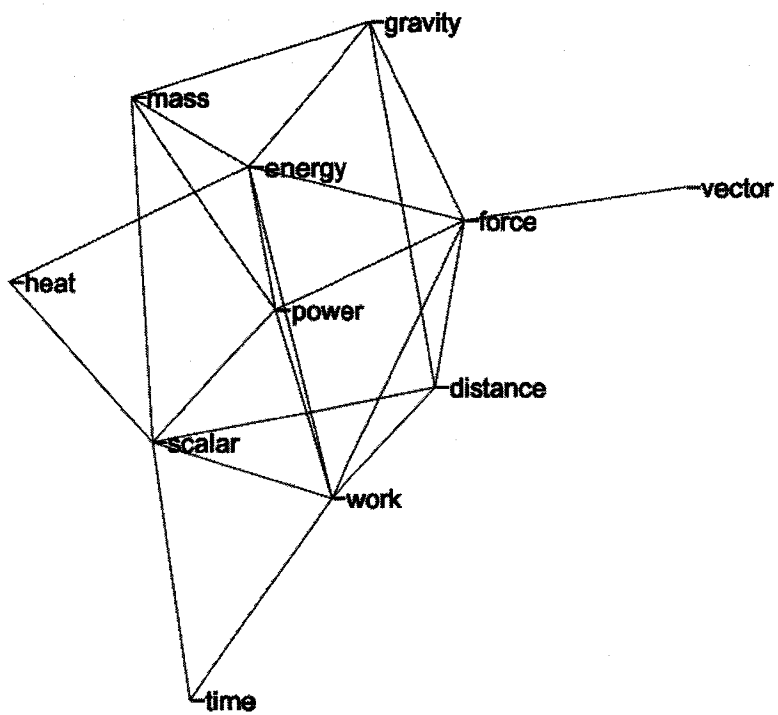
Student's Pathfinder network

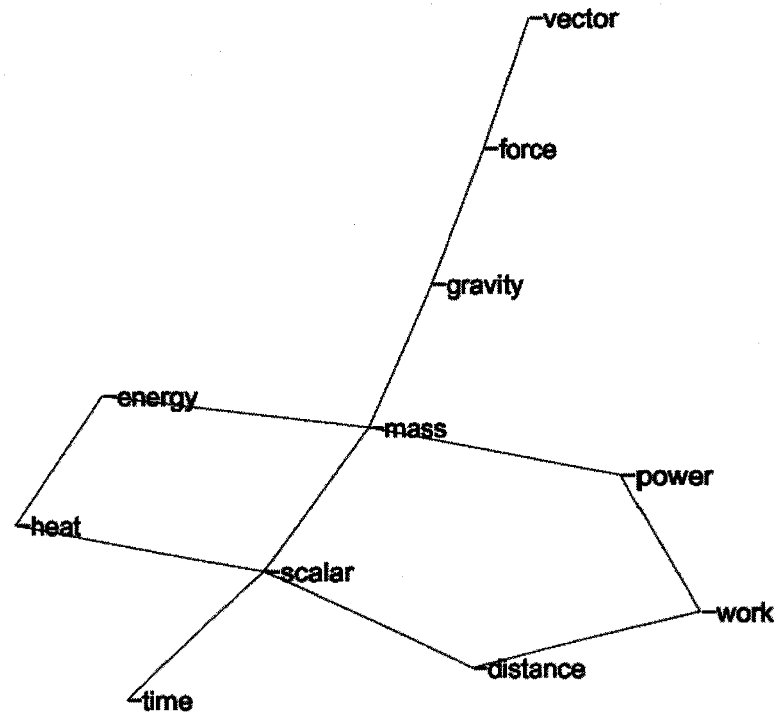


Student's modified Pathfinder network

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "power", "distance", "force" and "energy". Many expert scientists think that the concept of "work" is also strongly related to the concept of "scalar". Can you think of ways in which "work" is strongly related to "scalar"?

Student-13's Pathfinder network

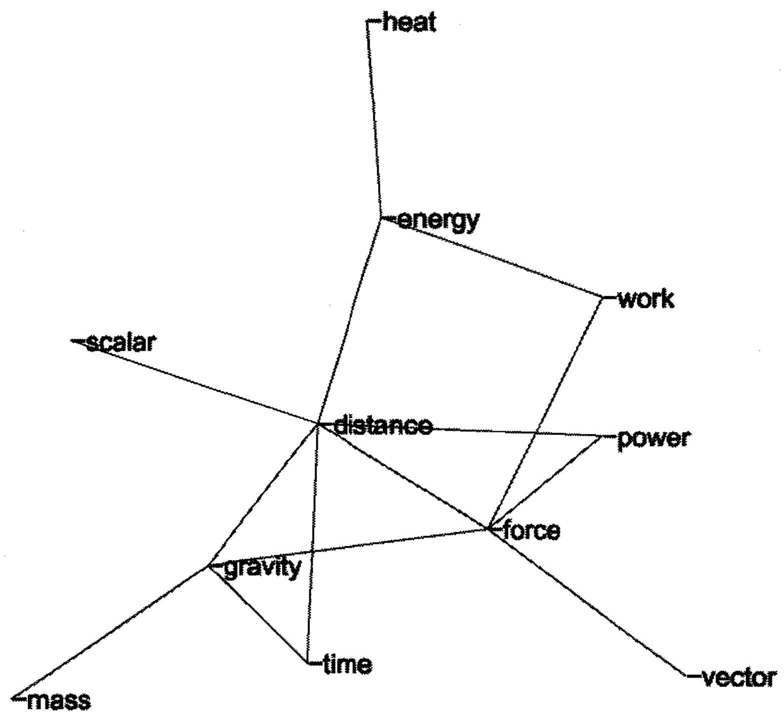


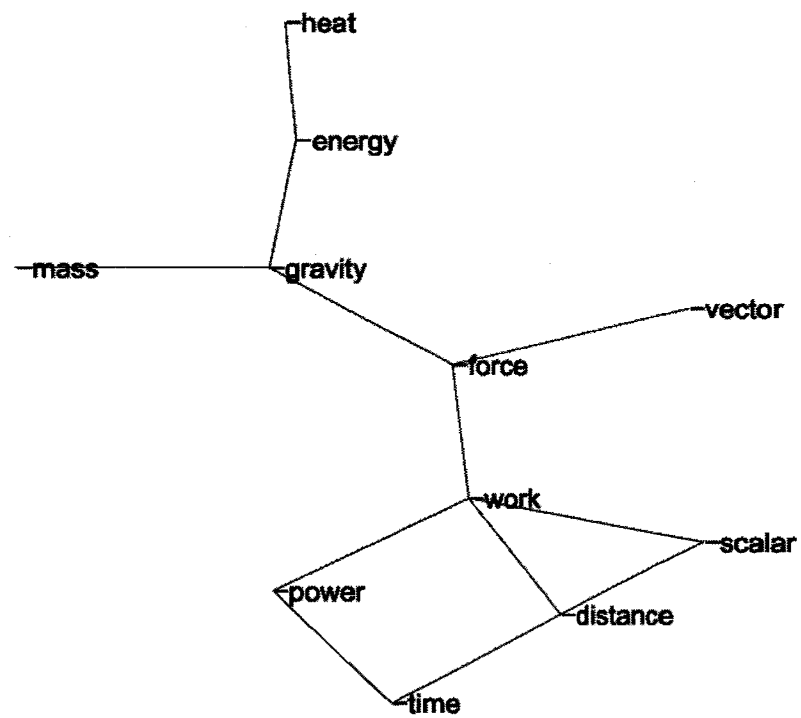


Student's Pathfinder network **Student's modified Pathfinder network**

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance", "force", "power", "energy", "scalar" and "time". Many expert scientists do not see the concepts of "work" and "time" as being quite as strongly related. Can you think of ways in which "work" and "time" are NOT very strongly related?

Student-14's Pathfinder network

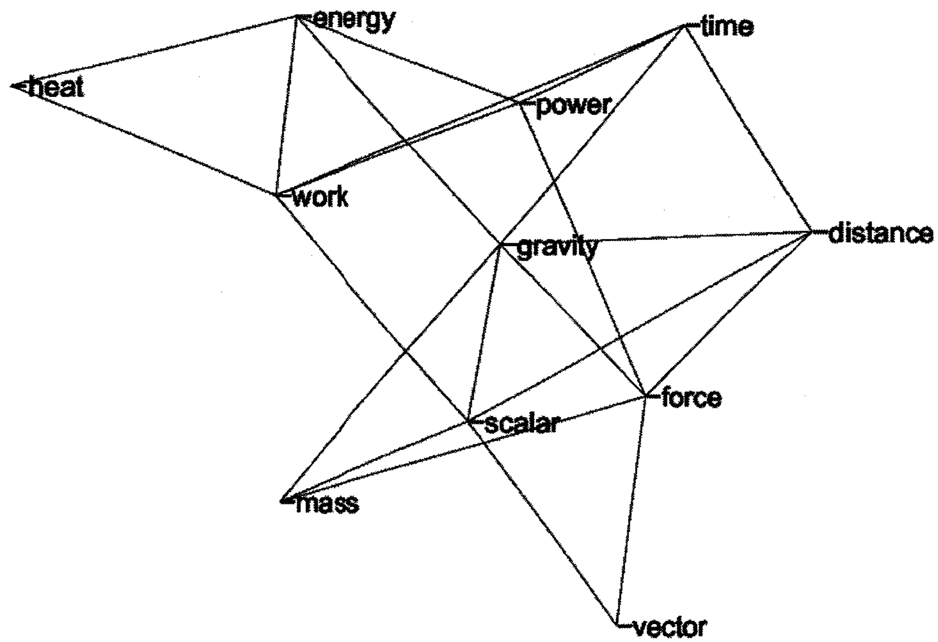




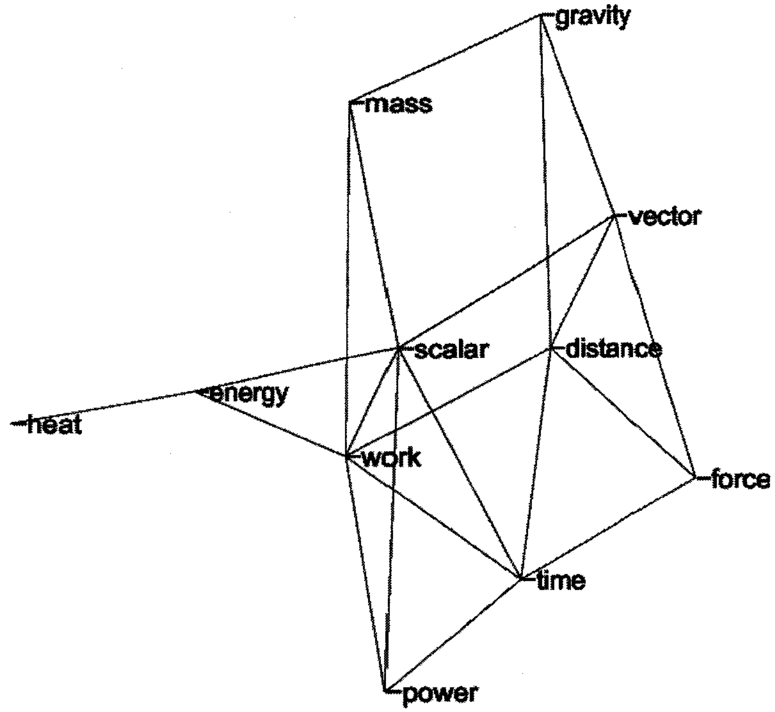
Student's Pathfinder network **Student's modified Pathfinder network**

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "energy" and "force". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power", "distance" and "scalar". Can you think of ways in which "work" is strongly related to "power", "distance" and "scalar"?

Student-15's Pathfinder network



Student's Pathfinder network

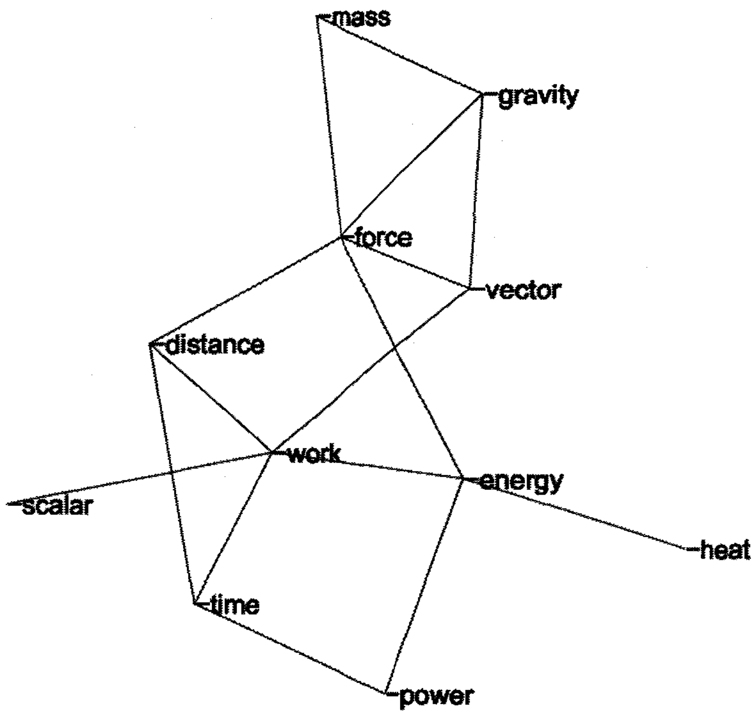


Student's modified Pathfinder network

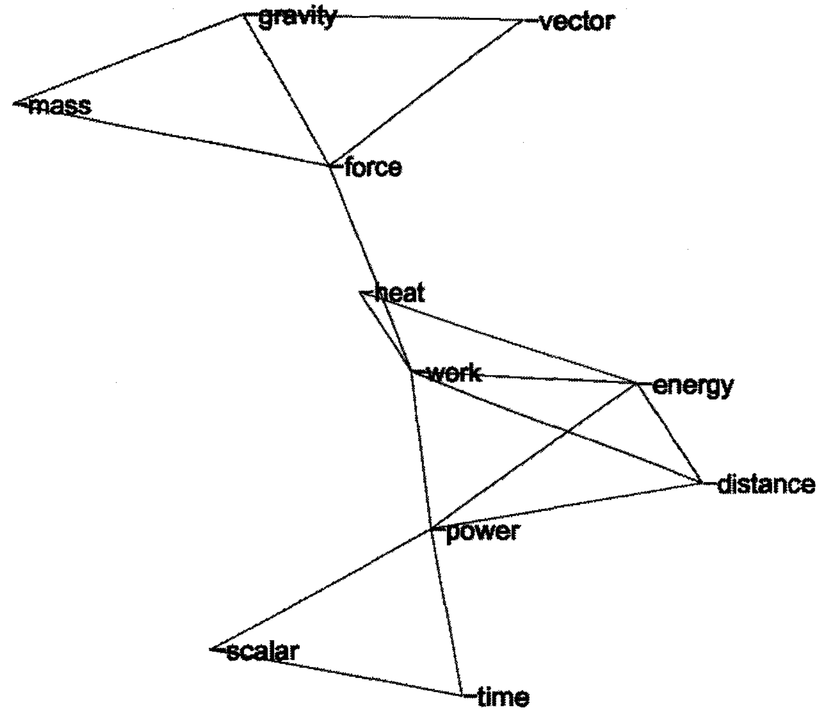
Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "power", "energy" and "scalar". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "distance" and "force". Can you think of ways in which "work" is strongly related to "distance" and "force"?

Your ratings also indicate that you see the concept of "work" as being relatively strongly related to the concepts of "time" and "heat". Many expert scientists do not see these concepts as being quite as strongly related to the "work". Can you also think of ways in which "work" and "heat" are less related as compared to "work" and "energy", and the concept of "work" is NOT very strongly related to "time"?

Student-16's Pathfinder network



Student's Pathfinder network

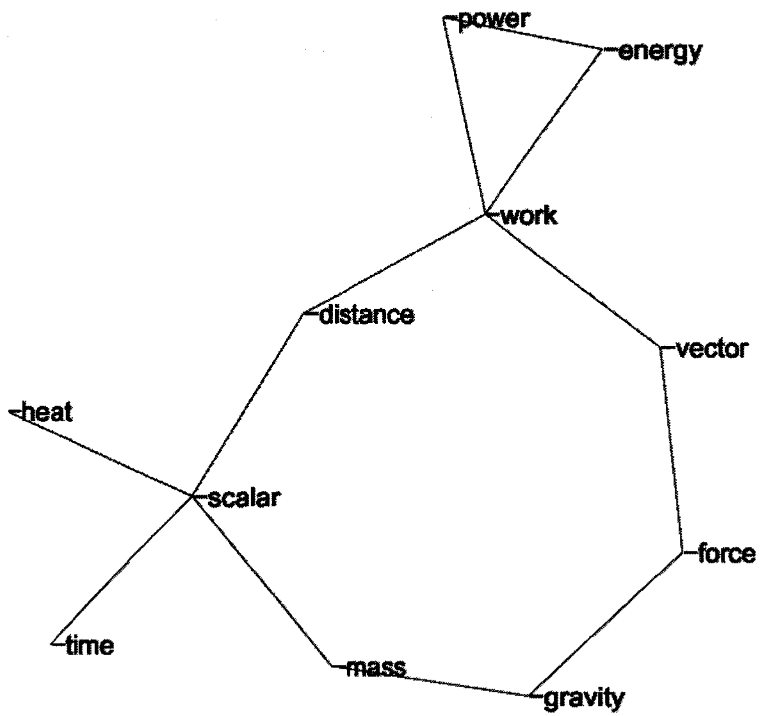


Student's modified Pathfinder network

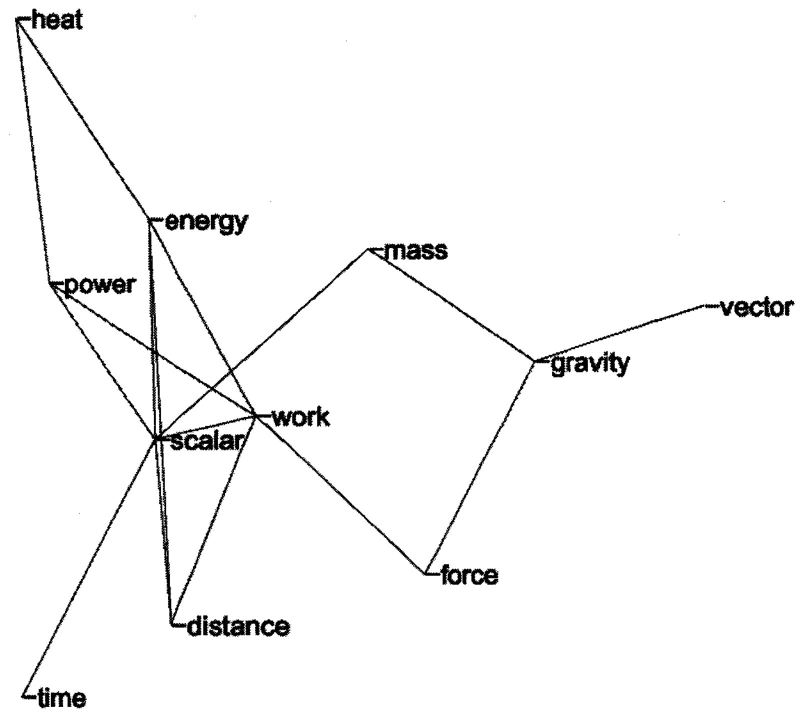
Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance", "energy" and "scalar". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power" and "force". Can you think of ways in which "work" is strongly related to "power" and "force"?

Your ratings also indicate that you see the concept of "work" as being relatively strongly related to the concepts of "time" and "vector". Many expert scientists do not see these concepts as being quite as strongly related to "work". Can you also think of ways in which "work" is NOT very strongly related to "time" and "vector"?

Student-17's Pathfinder network



Student's Pathfinder network

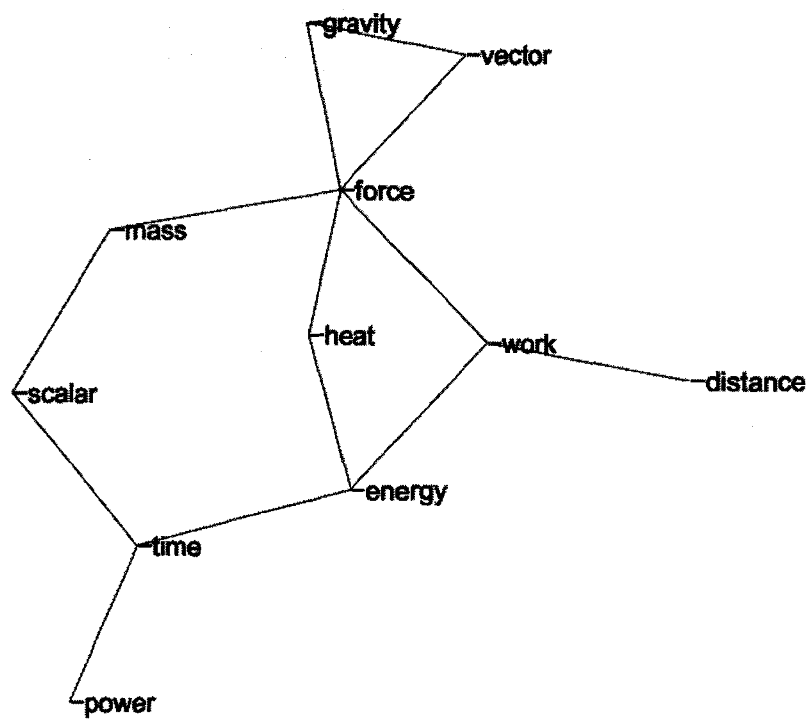


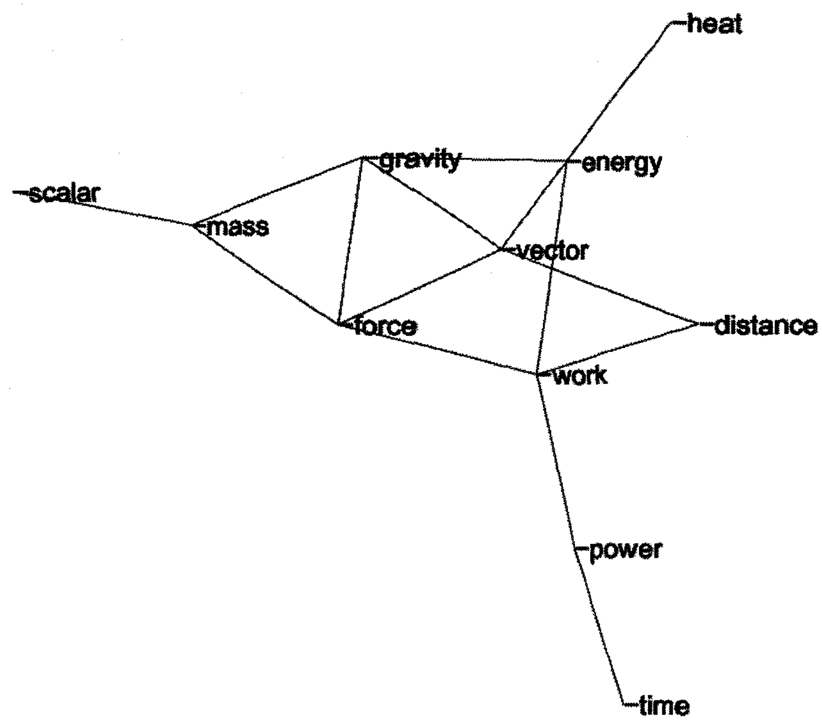
Student's modified Pathfinder network

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "energy", "power" and "distance". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "force" and "scalar". Can you think of ways in which "work" is strongly related to "force" and "scalar"?

Your ratings also indicate that you see the concepts "work" and "vector" as being relatively strongly related. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which "work" and "vector" are NOT very strongly related?

Student-18's Pathfinder network

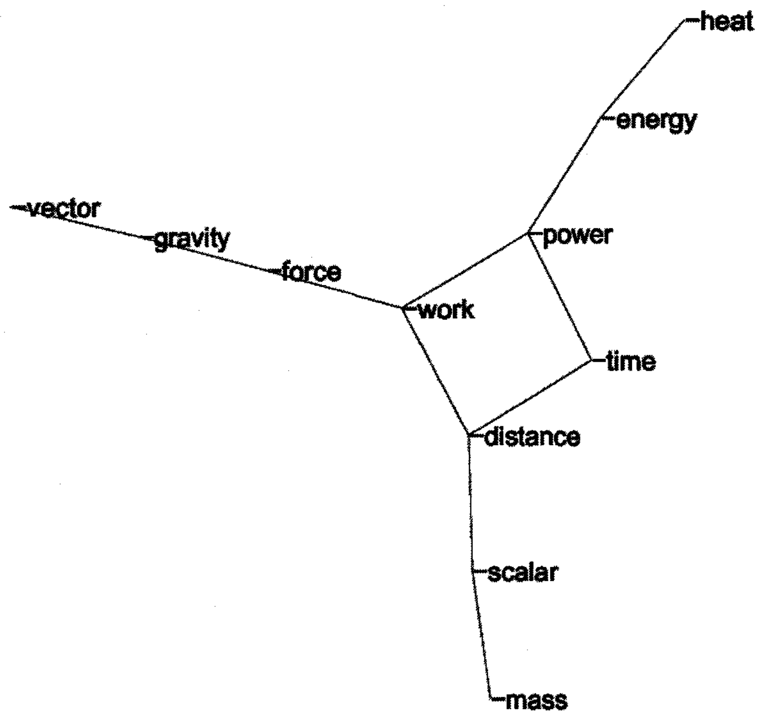




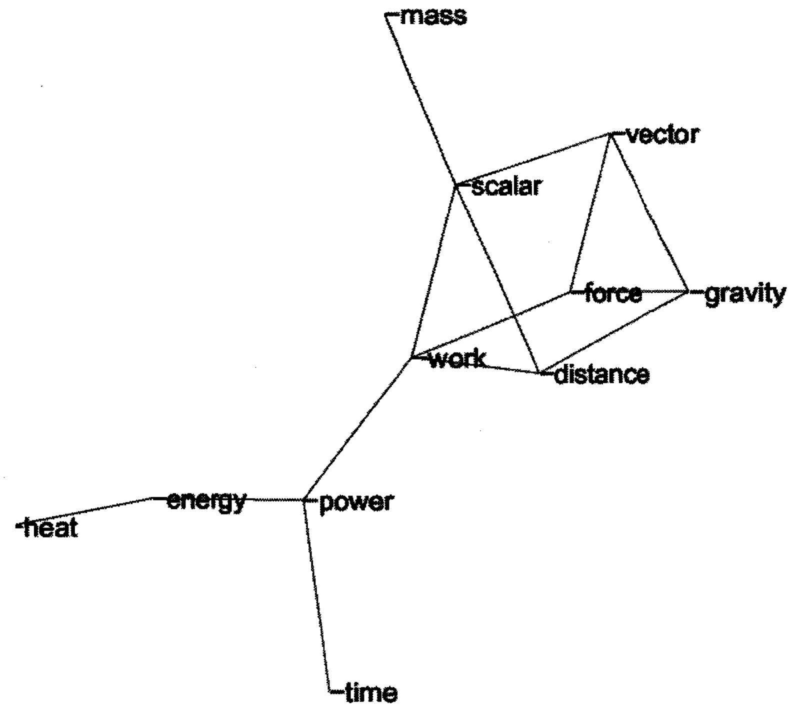
Student's Pathfinder network **Student's modified Pathfinder network**

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance", "force" and "energy". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power" and "scalar". Can you think of ways in which "work" is strongly related to "power" and "scalar"?

Student-19's Pathfinder network



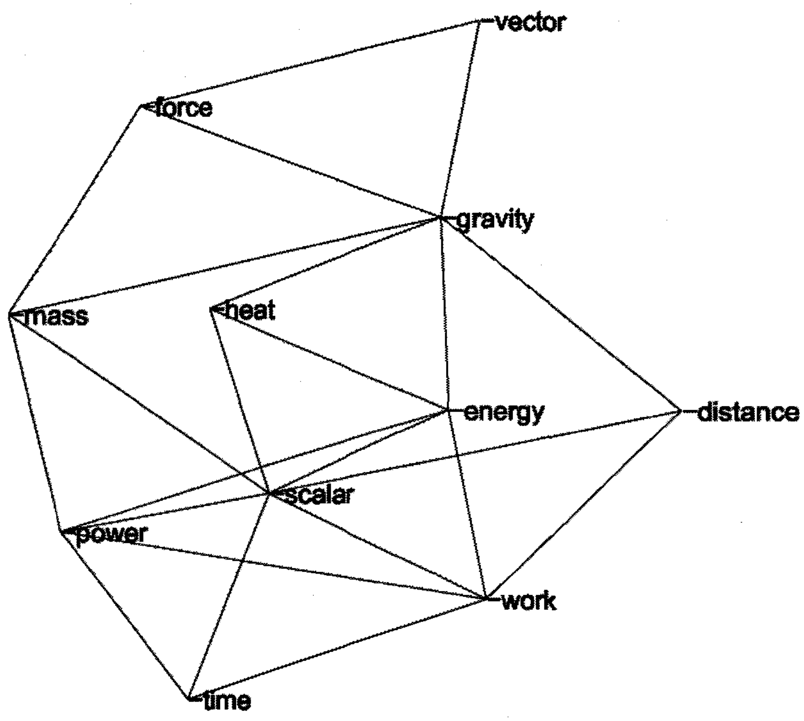
Student's Pathfinder network



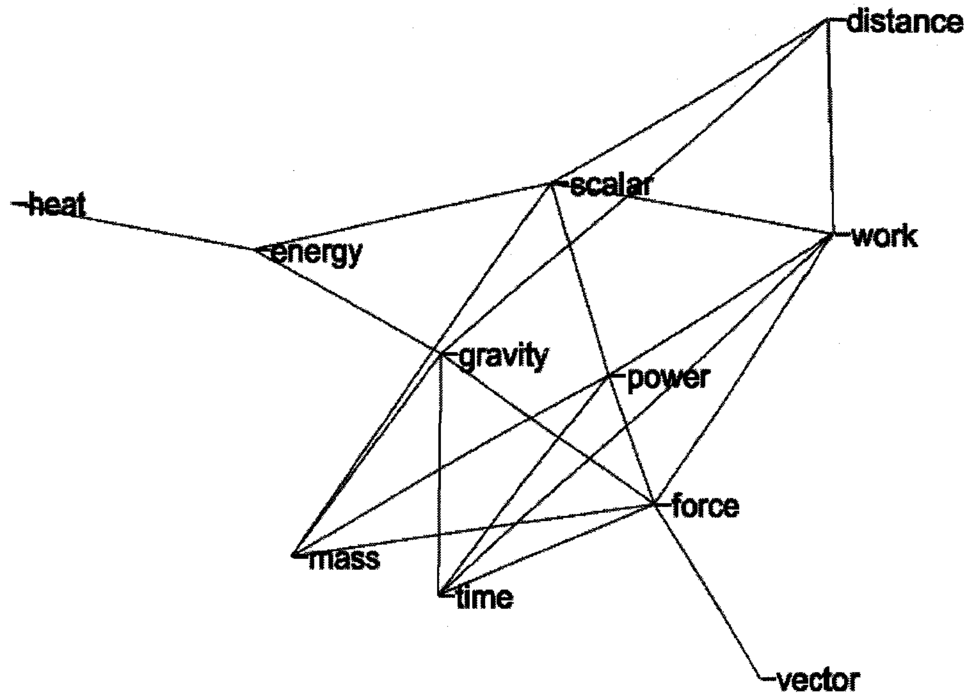
Student's modified Pathfinder network

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "power", "force" and "distance". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "energy" and "scalar". Can you think of ways in which "work" is strongly related to "energy" and "scalar"?

Student-20's Pathfinder network



Student's Pathfinder network

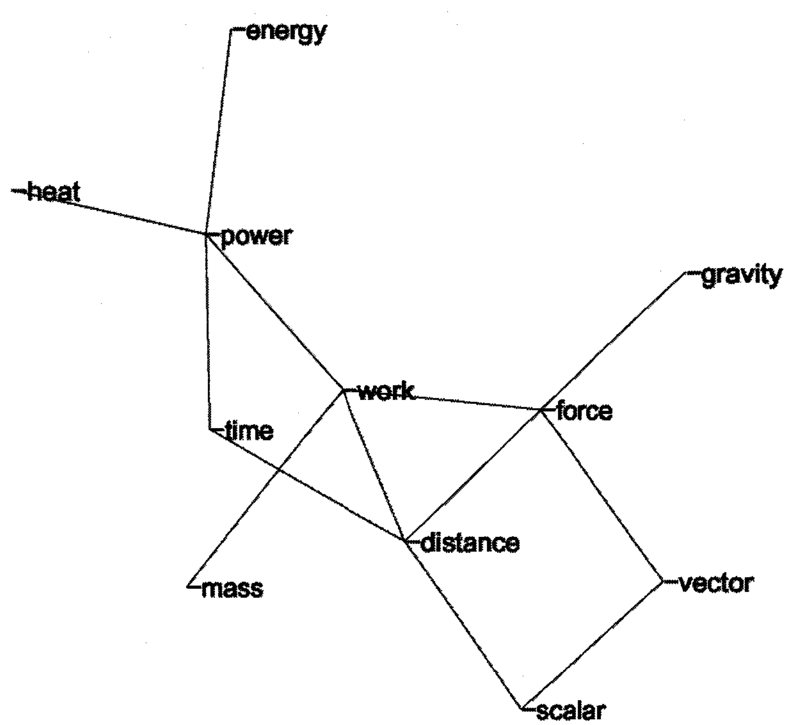


Student's modified Pathfinder network

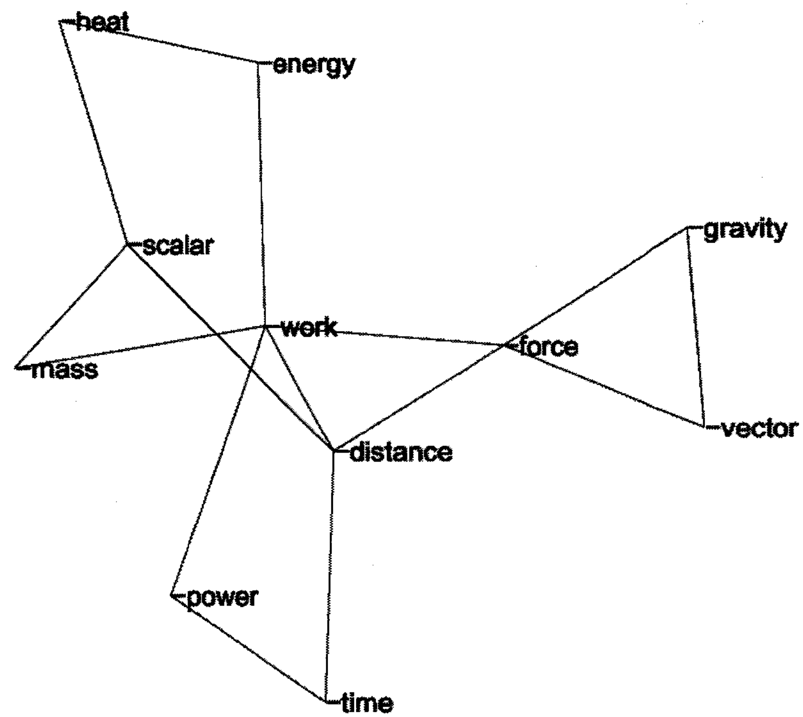
Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "power", "scalar", "energy" and "distance". Many expert scientists think that the concept of "work" is also strongly related to the concept of "force". Can you think of ways in which "work" is strongly related to "force"?

Your ratings also indicate that you see the concepts "work" and "time" as being relatively strongly related. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which "work" and "time" are NOT very strongly related?

Student-21's Pathfinder network



Student's Pathfinder network

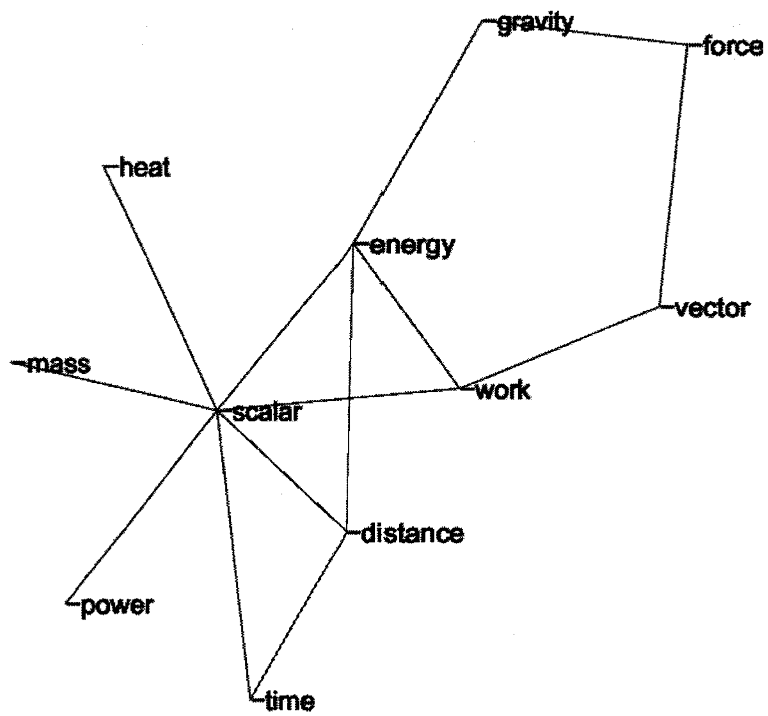


Student's modified Pathfinder network

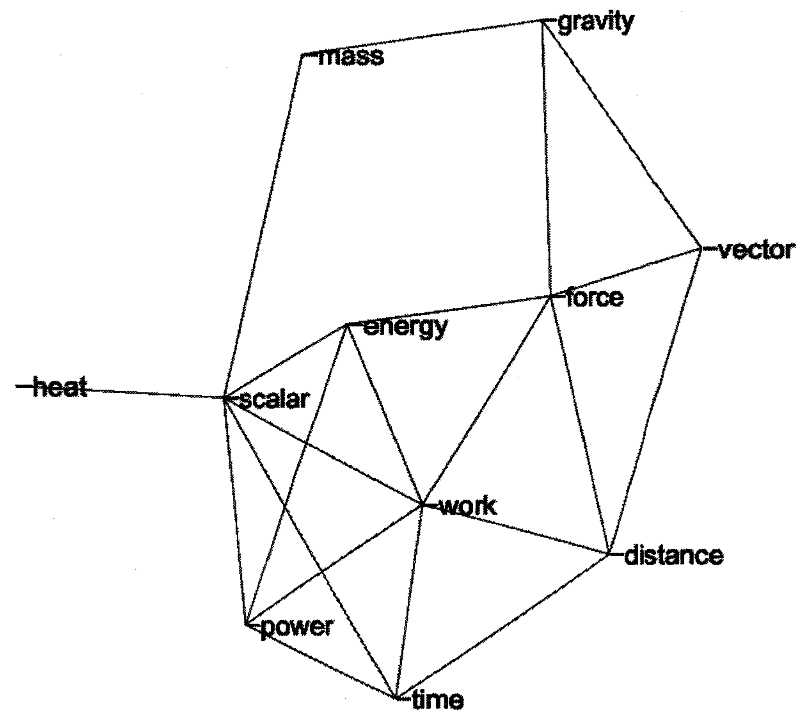
Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance", "force" and "power". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "scalar" and "energy". Can you think of ways in which "work" is strongly related to "scalar" and "energy"?

Your ratings also indicate that you see the concepts "work" and "mass" as being relatively strongly related. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which "work" and "mass" are NOT very strongly related?

Student-22's Pathfinder network



Student's Pathfinder network

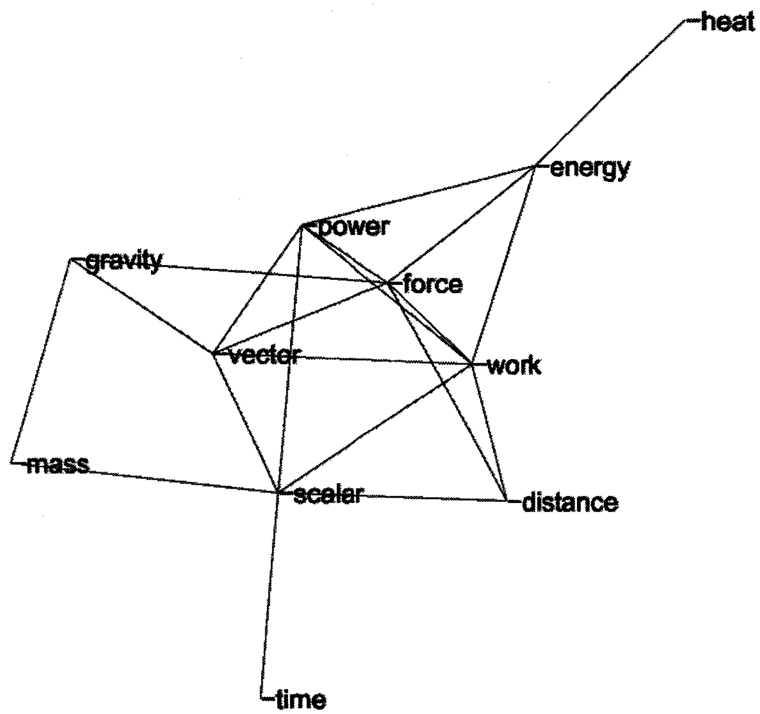


Student's modified Pathfinder network

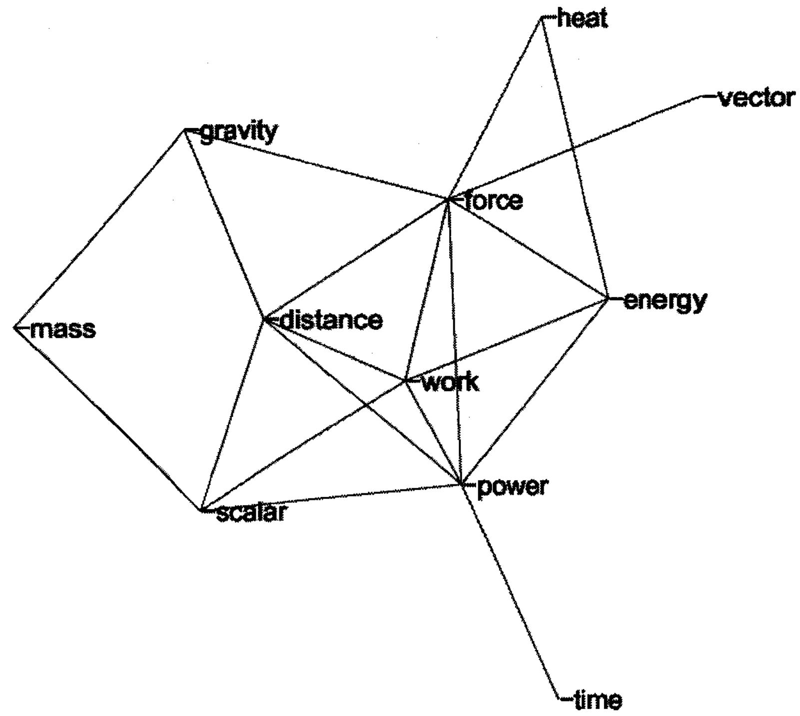
Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "energy" and "scalar". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power", "distance" and "force". Can you think of ways in which "work" is strongly related to "power", "distance" and "force"?

Your ratings also indicate that you see the concepts "work" and "vector" as being relatively strongly related. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which "work" and "vector" are NOT very strongly related?

Student-23's Pathfinder network



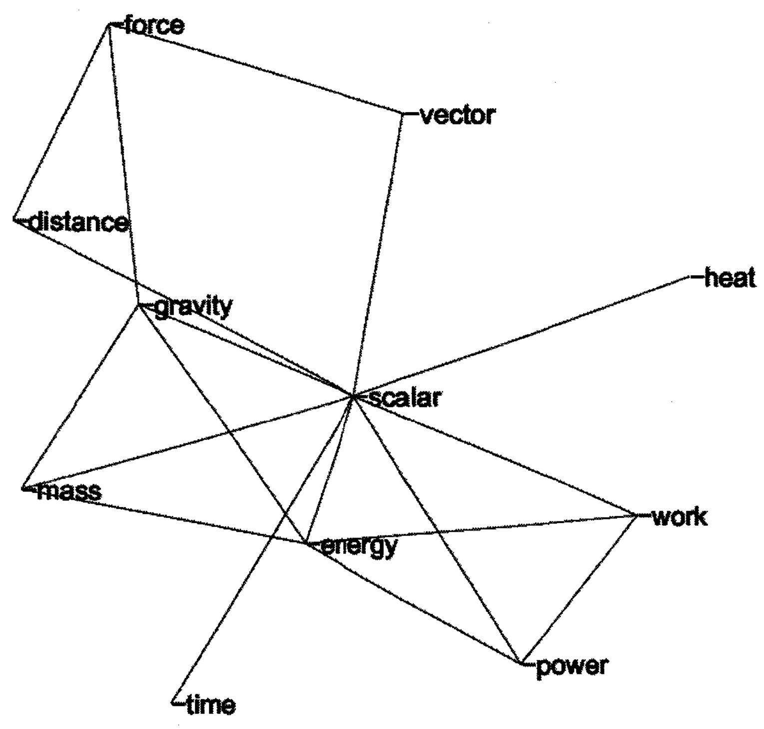
Student's Pathfinder network



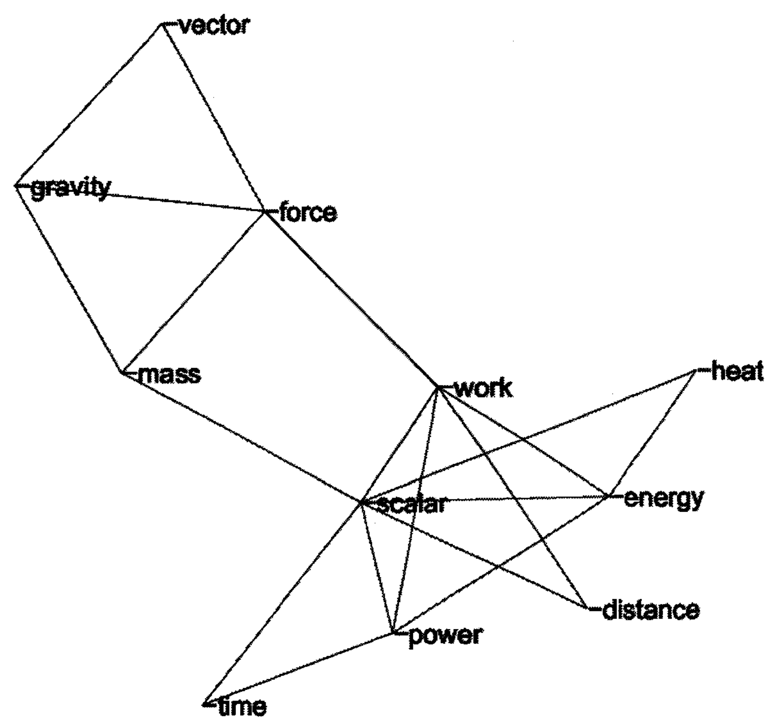
Student's modified Pathfinder network

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "distance", "scalar", "power", "force", "energy", and "vector". Many expert scientists do not see the concepts of "work" and "vector" as being quite as strongly related. Can you think of ways in which "work" and "vector" are NOT very strongly related?

Student-24's Pathfinder network



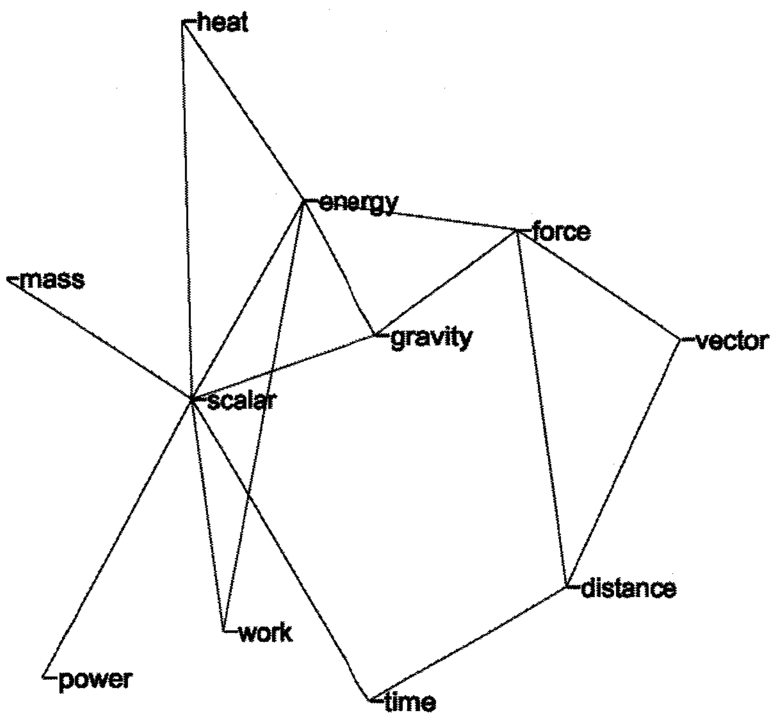
Student's Pathfinder network



Student's modified Pathfinder network

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "energy", "power" and "scalar". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "distance" and "force". Can you think of ways in which "work" is strongly related to "distance" and "force"?

Student-25's Pathfinder network

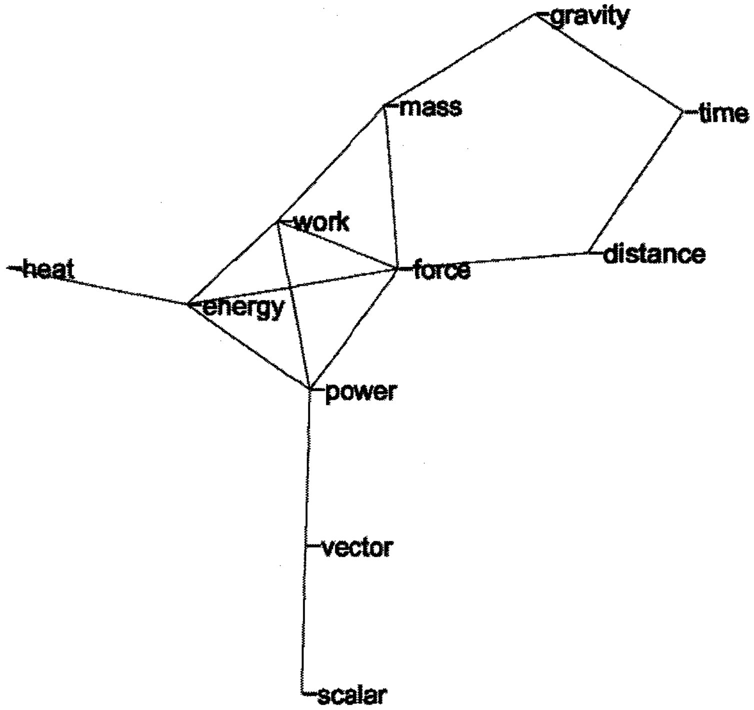


Student's Pathfinder network

Student was absent during the second ratings

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "energy" and "scalar". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "power", "distance" and "force". Can you think of ways in which "work" is strongly related to "power", "distance" and "force"?

Student-26's Pathfinder network



Student's Pathfinder network

Student was absent during the second ratings

Instructions given to the student: Your ratings indicate that you see the concept of "work" as being relatively strongly related to the concepts of "force", "power" and "energy". Many expert scientists think that the concept of "work" is also strongly related to the concepts of "distance" and "scalar". Can you think of ways in which "work" is strongly related to "distance" and "scalar"?

Your ratings also indicate that you see the concepts "work" and "mass" as being relatively strongly related. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which "work" and "mass" are NOT very strongly related?

Expert's Averaged Pathfinder network