

**Comparing the Effect of Reflections, Written Exercises, and Multimedia Instruction to Address
Learners' Misconceptions using Structural Assessment of Knowledge**

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Abstract

The study assessed the knowledge structure of Grade 11 physics students and their instructors using Pathfinder networks. Instructors' structural knowledge was averaged to create a referent pathfinder network. Each student's pathfinder network was compared with the referent pathfinder network in order to identify misconceptions. These misconceptions served as the basis for remedial instruction.

The study was conducted in six sections of Grade 11. Three different types of remedial instruction based on three different chapters from the Grade 11 physics textbook were given to the students at three separate stages. In the first section, students were shown their own and referent pathfinder networks as an intervention during the first stage. The students were asked to reflect on the similarities and differences between them. The researcher gave written concept-oriented exercises based on the differences at the second stage, and multimedia concept-oriented instruction based on the differences was given to the students at the third stage. The order of instruction was counterbalanced in all the six sections. After each stage, students' pathfinder networks were reassessed and the similarities between students' and the referent pathfinder networks were calculated to measure the effect of a particular intervention. The study tried to determine which type of remedial instruction given to students best improved the knowledge structure of the students in the domain of physics.

Results revealed that the similarity indices around the treatment concepts in the pathfinder networks of the students increased the most from pre- to post-intervention phase because of their reflections, followed by multimedia concept-oriented instruction and written concept-oriented exercises. Most likely, the major reason for this change was the interventions around the treatment concepts by the researcher at three different stages which stimulated and

probably changed some of students' misconceptions. To address the issue of validity, the similarity indices of control concepts in the students' pathfinder networks were also checked for improvement. The result shows that there is no appreciable improvement in control concepts as there was no intervention around those concepts. Findings support the use of structural assessment of knowledge with pathfinder scaling technique to check the effectiveness of a classroom instruction.

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INTRODUCTION

Definition and Review of the term Misconception

Students generally derive their conceptions in the domain of science from their own everyday experiences. These everyday experiences could be their casual observation of the world, reading a textbook, the Internet, or any other electronic media, or information gained from parents, siblings and friends. Osborne and Wittrock (1983) reviewed the research on student conceptions in science and state 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). Such students’ knowledge is commonly referred to as children’s science (Osborne & Freyberg, 1985), preconceptions (Ausubel, Novak, & Hanesian, 1978), naïve theories (Resnick, 1983), conceptual primitives (Clement, 1982), private concepts (Sutton, 1980), alternative frameworks (Driver, 1981), and alternative conceptions (Gilbert & Watts, 1983; Özmen, 2004; Pakua, Treagust, & Waldrip, 2005). When those conceptions are seen to be in conflict with the accepted meanings in science, the term *alternative conceptions* or *misconceptions* (Nesher, 1987; Perkins & Simmons, 1988) is often used. The term misconception is the most traditional term to represent concepts that are at variance with scientifically accepted knowledge in science education and will, therefore, be used in this thesis. Although the connotation of “misconception” may be considered negative to some (Minstrell, Anderson, Kraus, & Minstrell, 2008), it still represents an effort by a learner to form and organize ideas to understand the world around him/her. The success of this effort depends both on the developmental stage of the learner and exposure of the learner to new experiences and new knowledge (Urdan, & Maehr, 1995).

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 define 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 defined as 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 often have many misconceptions. For example, Halloun and Hestenes (1985) analyzed common sense beliefs of students about motion and its causes, and found that many students think that heavier objects fall faster. Hewson (1985) observed misconceptions among students at different educational levels about the relatedness

between concepts of velocity and position and found that students generally think that when two objects are at the same position, their velocities are equal. Whitaker (1983) found that physics students have many misconceptions about trajectory motion. Some other common examples of misconceptions in physics are:

1. Force of the hand acting on a coin tossed in the air moves with the body. 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.

As a teacher of physics for 12 years, I observed many of these misconceptions first hand among my students.

How do Students develop Misconceptions?

Misconceptions are usually acquired at a young age to construct a way of making sense of an unfamiliar and complex world. 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. 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 (Baser & Geban, 2007; Hameed, Hackling, & Garnett, 1993). 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 that may impede conceptual change can be the lack of background knowledge or the lack of will to re-evaluate information. Misconceptions may hinder conceptual understanding of a student if left unaddressed. Therefore, teachers must apply effective instructional strategies to address misconceptions that students have if they want to alter them.

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. As well, everyday language influences the development of concepts (Vygotsky, 1997), as the meanings of words in our everyday language may be contradictory to their scientific terms (Kikas, 2003). This contradictory meaning is the most common source of misconceptions among students. For example, the term *elasticity* has one meaning in lay conversation (“the stretchier the more elastic”) and an exactly opposite meaning in physics (“the greater the restoring force the greater the elasticity”). As a consequence, students working with the first definition develop misconceptions. The definition of the term *work* ($\text{work} = \text{force} \times \text{displacement}$) 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 in colloquial usage, as do English people (BBC, 2008, July 11), although the two terms have different definitions in the context of physics. The descriptions of misconceptions stated above in some cultures may be extended to other cultures too and it can be stated that similar misconceptions occur in all cultures. But the particular examples/analogies/problems that are used to address these misconceptions may need to be unique for different

cultures. For example, if students in two cultures study Newton's second law of motion using different examples—one using example of a rocket and other using example of a bullock cart—those students may develop different misconceptions in relation with objects used in those examples. But to address those misconceptions, instruction given to students about the principle followed by Newton's second law of motion (i.e., $F = ma$) need to be the same.

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 scientific concepts lies in their abstractness and detachment from reality. The process of learning, therefore, depends upon schemas a student already has. 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 teaching, then students are often unable to understand these scientific concepts and may develop misconceptions. New knowledge could help a student to attain conceptual understanding when integrated with the prior knowledge of a student. But misconceptions are developed when students integrate new information, learned at school, with their everyday experiences without any scientific explanation. 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 of Students having Misconceptions

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 simply accumulating more declarative and/or procedural knowledge. This organization or interrelatedness of concepts or facts in memory is called a *schema* (Eggen & Kauchak, 2007). Schema is also commonly referred as *knowledge structure* (Schank & Abelson, 1977). A *mental model* can be viewed as a process of constructing, testing, and adjusting a mental representation of a problem (Derry, 1996). Therefore, mental model includes a schema plus cognitive processes for manipulating and changing bits of knowledge stored in a schema. The goal of mental modeling is to construct an understanding of a phenomenon (Derry, 1996). In this process of understanding of a phenomenon, previously learned schema provide building blocks to understand a new context. 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, Harding, & Potgieter, 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.

McCloskey (1983) argued that people develop, on the basis of their everyday experience, remarkably well-articulated knowledge structures. 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 of some concepts. Other studies, however, show that students do not always develop well organized knowledge structures. Students with misconceptions construct different mental models by which they explain concepts and processes happening around them; indeed, they do so already as young children and before receiving formal instruction (Carey, 1985). These mental models usually contain misconceptions that are far from the scientifically correct ideas (Diakidoy, Vosniadou, & Hawks, 1997). 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 extent without having a real understanding of the concept. Hammer and Elby (2002) proposed that personal thinking of students may also affect their conceptual understanding. According to Hammer and Elby, 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 a sense of the basic principles underlying it; (2) the principles of physics explain the phenomena of the physical world; and (3) the process of learning physics leads to modifying one's own understanding.

Research in science education shows consistently that students with misconceptions are relatively unaware of conflicts between their knowledge bases (Guzzetti, Snyder, Glass, & Gamas, 1993). When the teacher asks students with misconceptions to elaborate a concept, they use 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 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). Although students activate and use their prior knowledge during the learning process, due to misconceptions they may fail to coherently incorporate new information into their prior knowledge. Research on students' misconceptions also shows that they are resistant to change (Baser & Geban, 2007; Hameed, Hackling, & Garnett, 1993) which also affects students' comprehension of new knowledge (Diakidoy & Kendeou, 2001; Kendeou & van den Broek, 2005). This results in the compartmentalization, rather than integration, of new and old 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).

Clement's studies provide classic examples of research on misconceptions in the early phase. Clement (1987) suggested that misconceptions might provide a good starting point for instruction and that conceptual change can be approached by means of bridging analogies. 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 a certain law or principle and the *target examples* which the students do not previously know but that impart the same idea as the anchoring examples. 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 (1987) 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 (i.e., the book on the table).

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 instruction 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). One of the intended purposes of this study is to benefit teachers' understanding of students' knowledge structures and thinking, which may lead to using improved pedagogy and instructional strategies.

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 domains of physics by Pine, Messee, and St. John (2001) to develop lists of 130 common misconceptions among students. Pine et al. recruited

122 primary science teachers for their study and asked them questions about science topics which children had difficulty with and the types of naïve ideas exhibited by the children. 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 are collected only from teachers, but not from the students themselves, so there is always a risk of not getting authentic information if the teacher misinterprets students' difficulties or fails to fully report students' misconceptions because of time constraints, lack of motivation, lack of attention, etc.

Some researchers have interviewed students directly. For example, Hamza and Wickman (2008) interviewed eight pairs of upper secondary students during a practicum on electrochemistry. The participant students gave a full description of the practicum during their interview. Hamza and Wickman (2008) found that the most commonly encountered misconception among students was about the direction in which electrons flow in the electrolyte. 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 in the field of electrochemistry. Using a constructivist approach, Acar and Tarhan tried to explain "why students bring misconceptions to chemistry classes and where these misconceptions come from" (p. 351). 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 reference. After further instruction, the instructor may want to know if students correctly change their conceptions. However, it is very difficult for an individual instructor to manage such a process of evaluation in which he or she has to use open-ended questions during interviews with every student in a class.

Multiple-choice tests are another way to analyze misconceptions among students. Baser and Geban (2007) administered a multiple-choice test to 72 students to understand the misconceptions among students in the domain of heat and temperature. Korner (2005) went a step further and analyzed the patterns in the incorrect answers on a multiple-choice test to identify 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 topics. However, in these types of tests the choices are fixed and the reason behind the wrong answer has to be assumed by the researcher.

Therefore, different methods of identifying misconceptions have different weaknesses and strengths. The three methods discussed above are largely employed for identifying misconceptions related to a specific topic. A concept mapping technique, described in the following section, can be used to visualize conceptions or misconceptions carried by the students around a specific concept through understanding learners' mental models.

Identification of Misconceptions using a Concept Map

A concept map is a visual representation of how concepts are related to each other. Trochim, who developed methodology for concept mapping (1985, p. 577), 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 and 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” (p. 1). Therefore, each concept is a node, connected to other related concepts by a link.

Concept mapping can be used as a methodology for organizing different ideas and concepts to evaluate conceptual understanding of an individual or a group of diverse people. Further, concept mapping can be used as an integrated mixed-method (Greene, Caracelli, & Graham, 1989) because its quantitative and qualitative components are quite interwoven. The quantitative and qualitative components of a concept map enable a researcher to determine frequency as well as explain misconceptions among students in different domains. Quantitative data is mostly based on numbers and a researcher interprets these numbers as total number of misconceptions a student has. The qualitative components of a concept map involve visual inspection of the concept map to see if the relationship among concepts drawn by a student is scientifically accurate. Through the qualitative component a researcher can explore crucial misconceptions that may be more problematic for conceptual understanding of a student. A researcher may represent their findings in a variety of ways to give awareness about crucial misconceptions. Goldsmith and Johnson (1990) showed that it is possible to discriminate qualitatively among students within a level of expertise and described these differences of performance along a quantitative continuum. An extensive amount of literature is also available on the use of concept maps to address misconceptions among students. For example, concept maps were administered over particular intervals to assess changes

in the knowledge structures of students about electricity (Anderson, Lucas, Ginns, & Dierking, 2000), high school science in general (Kinchin, Hay, & Adams, 2000), and biomedical engineering design of 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 correctness of links). These scoring methods have been shown to be valid with or without comparison to a master map (McClure, Sonek, & Suen, 1999), but there are strengths and weaknesses of each (Ruiz-Primo & Shavelson, 1996). One of the greatest concerns with any of the methods is that the quality of concept maps is dependent not only on students' domain knowledge but also on their skill with the technique. Students often require a great amount of instruction and support to learn concept mapping (Williams, 2004). Another limitation is that these scoring methods generate an overall score, but do not indicate the area of particular misconceptions. This is useful for a summative assessment purpose, but does not give enough information to design an improvement strategy or to give individualized feedback to a student. One comprehensive technique to generate mental models of individuals 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. A detailed discussion about Pathfinder networks will be done in the next chapter.

The Organization of the Thesis

The thesis is organized in four chapters followed by a reference section and appendices.

Chapter 1 of this thesis provides a review of the literature related to the field of procedural knowledge, conceptual knowledge and structural knowledge. This chapter further discusses pathfinder networks as a tool to assess structural knowledge of a learner and how instructors and

students differ in terms of their knowledge organization. Next, three types of remedial instructions to improve students' performance will be discussed. This literature review provides a conceptual framework of the hypotheses to be investigated in this study.

Chapter 2 details my methodology or what I actually did to conduct this research project. This includes the information about instructor and student participants, sets of concepts used during the data collection process, criteria to exclude outlier instructors and students, the research design, data collection instrument, and the methods of data collection.

Chapter 3 focuses on the testing of the hypothesis postulated in this study. The chapter presents a description of how the data was analyzed, which comprised of pre- post-intervention of similarity indices with the referent pathfinder network around a selected treatment concept. The similarity indices were calculated both around treatment and control concepts of 133 students. Finally the effect of three types of instructions (i.e., reflection, written exercises, and multimedia instruction) was analyzed using quantitative approach.

Chapter 4 concludes this research project. The conclusion presents a brief discussion of my research findings and what I have contributed to the knowledge base as a result of my work on this study. This final chapter also includes limitations of this research project.

CHAPTER 1: LITERATURE REVIEW

This chapter describes literature relevant to the research questions postulated in the study. The surveyed literature spans several disciplines including procedural knowledge, conceptual knowledge, structural knowledge and their assessments. I also described how degree of similarity between two pathfinder networks is determined and later on reviewed major fields in which pathfinder networks are being used. The primary objective is to organize and synthesize the existing literature and to understand the potential to give three different types of remedial instructions to students about their misconceptions seen using pathfinder networks. In light of misconceptions of students and different types of remedial instructions, two hypotheses are proposed.

Distinction between Procedural and Conceptual Knowledge

The relationship between procedural and conceptual knowledge has long been an important issue in science teaching because it seems to hold the key to learning processes and problem solving procedures. This relationship is extremely difficult to describe in its full extent (Rittle-Johnson, Siegler, & Alibali, 2001), because it changes over time and is determined by many forces, both internal and external to the learner. However, this knowledge distinction is useful for thinking about science learning. Such a distinction provides a way of interpreting the learning process that helps us better understand students' failures and successes. In this thesis, the issues will be examined by assuming the following knowledge distinction proposed by Kadujevich and Haapasalo (2001):

Procedural knowledge denotes dynamic and successful utilization of particular rules, algorithms or procedures within relevant representation form(s), which

usually require(s) not only knowledge of the objects being utilized, but also knowledge of the format and syntax for the representational system(s) expressing them.

Conceptual knowledge is characterized as knowledge that is rich in relationships. It can be thought of as a connected web of knowledge, the elements of which can be concepts, rules (algorithms, procedures, etc.), and even problems (a solved problem may introduce a new concept or rule) given in various representation forms.

Procedural knowledge is also defined as a student's ability to execute action sequences to solve problems (LeFevre, Smith-Chant, Fast, Skwarchuk, Sargla, Arnup, Wilger, Bisanz, & Kamawar, 2006, p. 286). In contrast to procedural knowledge, conceptual knowledge reflects a student's understanding of why a procedure works (Engelbrecht, Harding, & Potgieter, 2005) or of whether a procedure is legitimate in a given context (Rittle-Johnson, Siegler, & Alibali, 2001). Furthermore, conceptual knowledge provides an abstract understanding of the principles and relations between pieces of knowledge in a certain domain, whereas procedural knowledge enables us to quickly and efficiently solve problems (Baroody, 2003). This distinction between procedural and conceptual knowledge provides a framework to examine the relationship between the two kinds of knowledge as students' ability to solve problems. The notion is that cognitive skills of an individual develop through distinct stages, and students typically acquire procedural knowledge before they can effectively develop their conceptual knowledge (Davis, Gray, Simpson, Tall, & Thomas, 2000).

Learning science is essentially a constructive process. Students learn concepts of science not by absorbing definitions, theorems, and proofs, but by constructing them through their own intellectual efforts. Students enter school with highly developed informal problem-solving abilities (Marshall, 2006) and they use this informal knowledge in their problem solving

strategies (Mulligan, Mitchelmore, & Prescott, 2005). The flexibility of the procedures that students follow to solve a problem is the outcome of their informal knowledge, deep engagement with the concepts involved and use of efficient procedures (Groves & Doig, 2002). This flexibility is characterized by a rich and expanding network of relationships between problems, procedures for solving problems, and arithmetic operations. Therefore, by using flexible strategies to solve a problem, students recognize that different procedures are equivalent and can be used to solve the same problem and that different problems can be equivalent and can be solved with the same procedure (Marshall, 2006). Thus, not only do students learn more than one procedure, they also learn that they need to pay explicit attention to the conditions under which one or the other procedure would be advantageous (Schmittau, 2004). Consequently, students develop an integrated network of relationships between problems and strategies, representations, and efficient and effective problem solutions. Students do not learn scientific procedures as separate specific concepts, but as a system of interrelated concepts. As students learn new concepts, their knowledge structures become increasingly interconnected, and this integration permits more efficient problem solving (Baroody, Tiilikainen, & Tai, 2006). As existing knowledge is used routinely, it can serve as the data for the next, more complex problem solving strategies.

Assessing Procedural Knowledge

The basic procedure for assessment of procedural knowledge is straightforward. On each assessment occasion, the teacher gives the students a test asking some tasks, like solving a problem, performing an analysis, carrying out an equation, physically performing a procedure, etc. The results provide the teacher with the picture of students' current procedural knowledge in a particular domain. The assessment of classroom knowledge in these types of conventional tests is usually measured in terms of the percentage of correct answers by students. In some cases

students' performance may be analyzed into subscales, but mostly classroom learning is represented in terms of a 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 knowledge. They argue that the percentage of correct procedures or correct answers may be appropriate for certain types of knowledge where the conceptual relationship among the knowledge elements is not relevant. For example, a student's knowledge of the names of Canadian provinces and territories does not involve any conceptual relationship. It is appropriate to evaluate such knowledge in terms of the number of correct names of Canadian provinces and territories answered by students. In such cases, it is reasonable to assume that the "facts" comprising the domain are independent and additive (Goldsmith & Johnson, 1990). But conceptual knowledge involves the relationship or the organization of elements within a certain domain. This type of knowledge is usually not assessed and represented in typical classroom testing. Sometimes, teachers construct a classroom test that assesses conceptual understanding of students, but creating such a test is very time consuming. A traditional testing system may be very convenient in assigning grades to students, but it is less efficient to analyze the conceptual understanding a student has. 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).

Structural Knowledge and its Assessment

Structural knowledge refers to an understanding of interrelationship of concepts within a domain (Diekhoff, 1983). Therefore, it is also known as mental model, schema, and conceptual framework (Jonassen, Beissner, & Yacci, 1993). It has also been referred to as cognitive structure, the pattern of relationships among concepts in memory (Preece, 1976). Cognitive

science suggests that the organization of learned knowledge is of greater importance than the total amount of knowledge acquired by a learner for problem solving (Day, Arthur, & Gettman, 2001). This interrelatedness of knowledge is an indicator which identifies thinking and practices of an expert. 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.

Structural assessment of knowledge refers to a procedure for evaluating the organization of an individual’s knowledge within a particular domain (Trumpower, Sharara, & Goldsmit, 2010). This evaluation of the organization of knowledge involves eliciting students’ understanding of concept relations (i.e., their knowledge structure) and representing it graphically. The resulting graphical representation can be generated directly by the student as with concept mapping (Novak, 1990a,b; Trochim, 1989a), or indirectly by applying a scaling algorithm to student ratings of concept relatedness as with Pathfinder networks (Azzarello, 2007; Schvaneveldt, 1990). In either case, the student’s knowledge structure can be evaluated in comparison with a referent knowledge structure derived from domain experts. Similarity between student and referent knowledge structures has repeatedly been shown to be a valid measure of structural knowledge (Azzarello, 2007; d’Appolonia, Charles, & Boyd, 2004; Day, Arthur, & Gettman, 2001; Goldsmith, Johnson, & Acton, 1991; McGaghie, McCrimmon, Mitchell, Thompson, & Ravitch, 2000).

Structural Assessment of Knowledge and Pathfinder Networks

Concept mapping is a 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) and relationships among the concepts can be displayed. *Pathfinder networks* (abbreviated *PFnets*) were the result of such an effort to develop network models to represent knowledge from proximity data during the year 1981 (Schvaneveldt & Durso, 1981). Pathfinder is a computer-based network scaling technique that offers a quantitative method for representing and evaluating structural knowledge (Azzarello, 2007). 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, such as relationship among human experiences, relationship among human and objects, relationship between causes and effects, etc. 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 evaluation.

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 a 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 evaluation 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.

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 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:

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

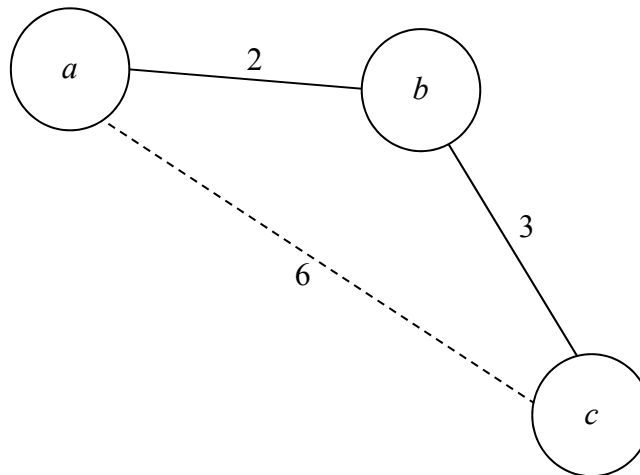
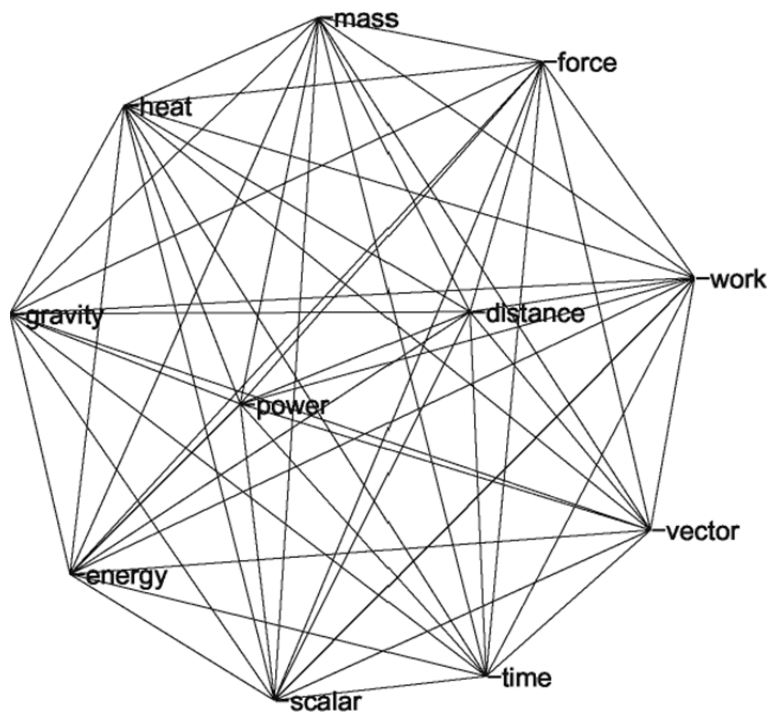


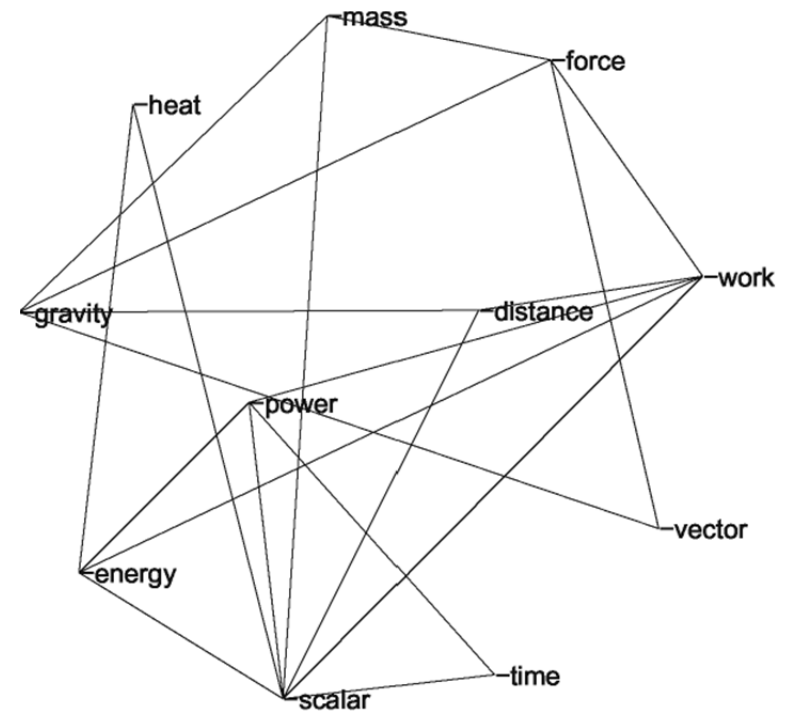
Figure 1.1. Generalized Triangle Inequality: The dotted line connecting nodes a and c violates triangle inequality.

As an example in Figure 1.1, 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). 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, because 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 parameters 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 1.2(a) shows a fully connected graph among 11 concepts where each concept is linked to all other concepts, the result is 54 links. On the other hand, Figure 1.2(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. "Similarity" is an example of such a useful function. *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 two PFnets (typically a student's and a referent) have in common (Goldsmith & Davenport, 1990).



(a) Fully connected PFnet with 11 concepts.



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

Figure 1.2. Two Pathfinder networks.

This function actually measures the similarity between two 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 neighboring concepts. Pathfinder compares each concept in two networks and then averages the results across the nodes to compute an overall similarity index. The 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)). The index 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 (Kudikyala, 2004). These cut-off values, however, 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. 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 instruction.

Pathfinder network methodology is rooted in the concept of semantic networks 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 or experts (generally instructor(s)) for misconceptions (Azzarello, 2007; Goldsmith & Johnson, 1990). 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 networks 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 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 related to tiger in the context of a zoo than in the context of jungle animals. In a series of studies examining the stability of instructors' PFnets of train locomotives, Gammack (1990) 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" (p. 226). 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 some variations, pathfinder is particularly useful in contexts where domain concepts are concise and remain relatively constant.

A considerable amount of literature relevant to pathfinder networks is available. This

literature is crucial for understanding the purpose and scope of pathfinder networks. Exploration and understanding of the purpose and scope help to situate the context in which the pathfinder network is used. Since their inception, pathfinder networks have been used for structural assessment of knowledge in diverse domains, including: physics (Sarwar, 2011; Trumpower & Sarwar, 2010), computer programming (Cooke & Schvaneveldt, 1988; Trumpower & Goldsmith, 2004; Trumpower, Sharara, & Goldsmith, 2010), computer networking (DiCerbo, 2007), problem solving in a puzzle story (Dayton, Francis, Durso, & Shepard, 1990), problems in cognitive modelling (Schvaneveldt, Dearholt, & Durso, 1988), statistics (Trumpower, 2010; Trumpower, Guynn, & Goldsmith, 2004), community health (Azzarello, 2007), mental health (Ober & Shenaut, 1999), pulmonary physiology (McGaghie, Boerger, McCrimmon, & Ravitch, 1996), pedagogical knowledge of teachers (Housner, Gomez, & Griffey, 1993), psychological research techniques (Goldsmith & Johnson, 1990), students' misconceptions about physiological responses (Michael, 1998), and flight training (Schvaneveldt, Beringer, & Lamonica, 2001). 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), software requirement understanding (Kudikyala & Vaughn, 2005), and designing interfaces for on-line help for UNIX operating system commands (McDonald, Paap, & McDonald, 1990).

Validity of Pathfinder Networks

Evidence for the validity of the 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 a 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 instruction, 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).

Effect of Instruction on Pathfinder Networks. Several studies have shown that there is a positive change in students' PFnets before and after instruction. For example, McGaghie, McCrimmon, Mitchell, Thompson, and Ravitch (2000) used pathfinder scaling to derive concept maps for medical and veterinary students and their physiology instructors. The concept maps were evaluated for student-instructor similarity. They found that students' PFnets become increasingly similar to instructor's PFnet from pre- to post-intervention in the field of pulmonary physiology. In another study, Azzarello (2007) used a one-group pretest-posttest design. Changes were examined in students' PFnets from the beginning to the end of a nursing course. The relationship between students' PFnets and their mean course examination scores were described, and the PFnets of high-performing and low-performing groups were compared. Azzarello 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. Students with structural knowledge that was most similar to the instructors' also performed better in the course. Findings were similar in studies of computer programming concepts (Trumpower & Goldsmith, 2004) and computer networking (DiCerbo, 2007).

Relationship Between the Similarity of Students' and Instructors' Pathfinder Networks and Classroom Achievement. Several studies also have shown a positive relationship between the similarity of students' and instructor's networks and students' test scores. Generally, students with structural knowledge that is similar to their instructor's perform better in the class. The students' structural knowledge can also differentiate between high-performing and low-performing students. For example, Goldsmith, Johnson, and Acton (1991) enrolled 40 college students taking the subject of statistics and design to judge the relatedness of 30 important concepts in the domain. Goldsmith et al. 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 a study of 53 undergraduate students enrolled in a teaching methodology course, Gomez et al. (1996) 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 positive and statistically significant. The study conducted by Azzarello (2007) examined the similarity 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 similarity. The mean examination score was positively correlated with post-course coherence and post-course similarity.

Pathfinder Networks and Diagnostic Assessment

Some recent studies also have shown that the utility of PFnets may be extended to diagnostic assessment. In a study of statistics problem solving, Trumpower, Guynn, and Goldsmith (2004) examined the processes underlying the goal specificity effect and the generality of knowledge acquired as a result of training with nonspecific versus specific goals. They 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 another recent study, Trumpower, Sharara, and Goldsmith (2010) used a simple custom designed programming language as a problem-solving domain. In their study, undergraduates with no prior training in computer programming learned about a simple computer programming language. Later, they were tested for their structural knowledge of the language, as well as their application of the language on a series of problem solving tasks. Trumpower et al. showed that the absence of specific links in students' PFnets can be used to diagnose misconceptions that lead to errors on specific types of problems in the domain. They identified two subsets of links (i.e., schemas) and used them to successfully predict performance on two different types of programming problems. Trumpower et al. (2008) further assert that in order to efficiently and effectively improve students' domain knowledge, instruction must be able to target these specific missing links and misunderstandings. Therefore, assessment of specific links in students' knowledge structures can be used to identify specific conceptual strengths and weaknesses. Using information about the conceptual weaknesses of students, an instructor may be able to give specific feedback to the students to improve their conceptual understanding.

Pathfinder Networks and Formative Assessment

What has emerged from the literature review is that pathfinder networks have shown their utility in a variety of applications over the last two decades, but almost all applications consider these networks as a unit to calculate network similarity of students and their instructor. These applications do not assess individual nodes or individual concepts separately. Although an overall measurement of the similarity of students' and their instructor's pathfinder networks gives an overall view about student's misconceptions, it does not focus on a particular

misconception a student has. Therefore, the overall measurement of the similarity of students' and their instructor's pathfinder networks is useful for summative assessment, it may be less useful for formative assessment. Pathfinder networks have been used to understand how students and experts organize knowledge, but the individual nodes generated by pathfinder networks could also be used to study misconceptions or weak conceptions about a particular concept in order to give specific feedback to students. That is, network similarity measures only indicate *how much* students' structures differ from an instructor's structure; they do not indicate specifically *in which subsection* structures differ. In addition to pathfinder networks' utility as a global measure of conceptual knowledge of students, my M.A. (Education) study was 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 demonstrated the potential utility of pathfinder networks for formative assessment and individualized learning. In my M.A. research project, I used pathfinder networks to formatively assess, and to create individualized interventions for, high school physics students around a treatment concept. The treatment concept and its links with other concepts in a student's network were compared to the same concept in the referent network to calculate a similarity index. The interventions were comprised of giving written feedback to the students on the differences between theirs and the referent pathfinder network around the treatment concept. As an intervention, instruction given to students to address their misconceptions was based on their reflections and individualized written exercises. Following the intervention, the study found a significant improvement in the students' knowledge structure by comparing pre- and post-intervention similarity indices. The results of the study only showed improvement followed the combined presentation of reflection and written exercises, but the improvement could either be due to the reflection, written exercises, or

both (Sarwar, 2011). The study did not determine which aspect of the intervention was responsible for the improvement in the similarity indices.

Conceptual Assessment and Remedial Instruction

Teacher-centered approach of teaching believes that the perception of a student is not different from a teacher (McDermott, 1993) because all the knowledge given to a student is by the teacher. Therefore, teachers' and students' conceptions should be the same. As various sources of knowledge are available to students via modern technology, students sometimes are more interested in getting information from other sources too. By doing so, they may not attain scientifically correct knowledge every time from all the sources available to them. Occasionally, they get impartial or incomplete information and through that incomplete information they may develop misconceptions.

One of the effective ways to address students' misconceptions is to challenge them using a constructivist approach in which the teacher may ask students for their written or oral response. With this approach of teaching, students may find a challenging environment for their misconceptions, which may lead to change some of them. To change students' 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.

The constructivist approach may encourage teachers to develop instruction to cater for

various conceptions and misconceptions of students. These instructions may challenge and empower students to alter their misconceptions. Among the various methods of constructivism, remedial instruction (Chan & Li, 2003) is of special importance in science teaching and learning. Remedial instruction offers opportunities for students to learn by confronting their own understanding and misconceptions. Remedial instruction also provides a bridge between the knowledge students already have and the new knowledge they are constructing. The relation between prior knowledge and new knowledge helps them to acquire new concepts on firm foundations and alter their misconceptions.

Lyster and Ranta (1997) used six different types of remedial instructions in the linguistic classroom to enhance students' learning. Their data was made up of transcripts totaling 18.3 hours of classroom interaction taken from 14 subject-matter lessons and 13 French language arts lessons. They found that four of the six types of instructions—elicitation, related comments and questions, clarification requests and teacher repetition of error, in that order—have considerable potential for some kind of repair to follow, either initiated by the learners themselves or by their peers. In a typical physics classroom, after giving feedback about misconceptions, remedial instruction to improve students' performance on assessments is usually given in a few different ways: students could be encouraged to give their reflection on a concept (Bandura, 2001; Chi, Bassok, Lewis, Reimann, & Glaser, 1989), the teacher can give written text and exercises to students to develop more knowledge around the concept (Svenson, Lawrence, & Willis, 1983), or the teacher can use multimedia clips and computer-based instruction to address the misconceptions of a student (Vicent, Avila, Anguera, Badia, & Montero, 2006), to name a few. There are a number of other types of instructions: peer tutoring, group discussion, direct instructions, project based learning, and problem based learning are common examples. The

techniques selected for this study, i.e., reflection, written exercises, and multimedia instruction act like an umbrella for other types of instructions. Peer tutoring can be used in a variety of context, with students teaching students, students teaching school pupils, non-professional adults teaching adults and children, and pupils teaching pupils. The three methods of instructions selected in this study can be used in such peer tutoring. In group discussion, students reflect and give reasons for their understanding to other members of the group. In direct instruction, teachers may use multimedia or written exercises to give more knowledge to students. Project based learning and problem based learning are built upon authentic learning activities that engage student interest and motivation. These activities are designed to make a project, answer a question or solve a problem. In project based learning or problem based learning each student always reflects on his/her understanding and then proceed further as a group. Therefore, techniques selected in this study embrace other methods of learning. The three types of remedial instructions are described in detail in the following three sections.

(a) Reflection

Reflection can be defined as “a generic term for those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations” (Boud, Keogh, & Walker, 1985). Reflection is a form of learners’ response in which they carefully explore their prior knowledge and experiences in relation to a specific concept, topic or issue. Through reflection a learner tries to clarify and create meaning of a topic during the learning process. Boud, Keogh, and Walker further argue that reflection can be done well or badly, successfully or unsuccessfully, but it is always a productive experience. John Dewey (1933) wrote much about his view on reflective thought and defines it as: “active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of

the grounds that support it and the further conclusions to which it tends” (p. 118). In every reflective activity, a learner confronts a problem, analyses the problem using his prior knowledge and draws a conclusion. Thus, while writing a reflection, students always think and try to integrate their prior knowledge with the topic under study. This deep thinking and revision of prior knowledge pays off. Training experiments indicate that there is a positive correlation between particular strategies students use to explain instructional materials to themselves in a classroom and students’ performance on associated problem-solving tasks (Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Pirolli & Bielaczyc, 1989; Pirolli & Recker, 1994). Chi (2000) also argues that self-explanation can aid in revising the mental model that students have of a problem or a text.

There are several objectives of having students write their reflections (Waddock, 1999). First, it provides students personal thinking about the interrelationship of concepts, which is sometimes missing from assignments, class presentations or term papers. Second, it engages students directly with the material designed by the experts and lets them think about the conceptual understanding of experts. Third, it moves students away from rote answers memorized from a textbook or given to them by a class teacher. Reflections can also enhance learning of science among students by producing cognitive and metacognitive skills (Baird, Fensham, Gunstone, & White, 1991). Metacognition refers to higher order thinking that involves an individual’s knowledge about his/her own learning processes, effectiveness of these learning strategies, awareness about the current learning tasks, and active control over the thinking processes involved in learning. Flavell (1976, p. 232) describes metacognition as “one’s knowledge concerning one’s own cognitive processes or anything related to them, e.g., the learning-relevant properties of information or data”. Metacognitive processes are central to

problem solving, planning, evaluation and many other aspects of learning. Baird (1986) argue that metacognition can be achieved in science classroom that may result in personal intellectual development.

Reflection has recently been emphasized as a constructive pedagogical activity (O'Reilly, Symons, & MacLachy-Gaudet, 1998; Roy & Chi, 2005). However, little attention has been given to the quality of reflections that students write. The students' reflections can be divided into the following three categories depending on the type of knowledge considered in those reflections: 1) conceptual, 2) procedural, or 3) declarative (Goldman & Hasselbring, 1997). Declarative knowledge reflects acquisition of specific facts and definitions of a subject. For example, memorization of the fact that Newton's Second Law states that force is equal to mass times acceleration denotes declarative knowledge. Thus, a student who uses declarative knowledge while reflecting on the relationship between force and acceleration might say that force and acceleration are related because Newton's Second Law says so. Although declarative facts/definitions are considered to be the building blocks with which higher forms of knowledge are constructed (Goldman & Hasselbring, 1997) they may be acquired without necessarily understanding their relationship with other facts and definitions (Apt, Blair, & Walker, 1988). As such, declarative knowledge-based reflections may lack critical thinking, relying instead on retrieval of isolated facts.

Procedural knowledge reflects an ability to utilize particular rules related to a concept – that is, to perform a procedure (Kadijevich & Haapasalo, 2001). Application of Newton's Second Law (e.g., solving a word problem by multiplying a body's mass times its acceleration to derive the force of the body) denotes procedural knowledge. A student who uses procedural knowledge while reflecting on the relationship between force and acceleration might say that they are related

because force is the product of mass and acceleration; therefore, as force changes, so must acceleration. [note slight distinction → declarative = definitional; procedural = experiential]

Conceptual knowledge reflects understanding of interrelationships among facts, procedures and concepts (Engelbrecht, Harding, & Potgieter, 2005). This understanding may encompass relationships between various bits of newly acquired knowledge, or between new knowledge and prior knowledge. Understanding that the relative difficulty in accelerating a 2000kg car and a 2kg toy car by the same amount is an illustration of Newton's Second Law is an example of conceptual knowledge. A student who uses conceptual knowledge while reflecting on the relationship between force and acceleration might say that they are related because in a car, the more force generated by the motor, the greater the car will accelerate. Although one might possess knowledge of facts and be able to perform certain procedures, it is conceptual understanding of how and why facts and procedures are related that allows new inferences to be drawn and transfer to new contexts to occur (Anderson, et al., 2004; Baxter, Elder, & Glaser, 1996; Trumpower & Goldsmith, 2004). As such, conceptual knowledge is considered to be a higher form of knowledge than declarative or procedural. It may be conjectured, then, that reflection focusing on conceptual knowledge is more effective than reflection focused on declarative or procedural knowledge.

(b) Written exercises

A critical goal of physics courses is to develop students' understanding of concepts and principles of physics. To attain this goal, typical coursework in physics includes lectures about the concepts of physics and problem solving around these concepts. Lang (1996) gives four reasons for integrating problem solving in the curriculum: it enhances learning, develops competent citizens, develops general problem solving competencies among students, and allows

students to apply problem solving skills learned in classroom to daily activities outside a school. Description of a procedure or method followed by a student to solve a problem also enables teachers to diagnose where the students face difficulties in applying their knowledge. Detailed diagnosis of errors committed by a student provides information to a teacher for specific intervention and remedial instruction (Clements, 1980; Newman, 1977; Radatz, 1979). Therefore, it seems fairly reasonable to think that students' working of physics exercises would yield information about their understanding of physics.

Written exercises are defined as studying or solving problems that illustrate a specific concept or a group of concepts and their interrelationship. One of the main goals of written exercises is to provide knowledge either procedural, conceptual or both through instruction and carefully designed numerical problems. The written exercises are 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). Sweller and his colleagues (e.g., Mawer & Sweller, 1982; Owen & Sweller, 1985; Sweller & Levine, 1982; Sweller, Mawer, & Howe, 1982; Sweller, Mawer, & Ward, 1983) investigated how students learn schemas through problem solving. Problem solving refers to a situation where a student solving a problem as a part of instructional sequence to learn concepts and principles of the subject being focused on in a classroom. In the process of solving a problem, a student uses scientific tools by following explicit rules set by their class teacher. Individual problem solving serves two goals: students seriously and attentively think about the given problem and become able to identify their own knowledge gaps. This concentration on individual problems makes them able to raise questions about their knowledge gaps in subsequent class activities. Cooper, Hanmer, and Cerbin (2006) found that problem solving

module help students to understand concepts taught in a classroom. In a traditional classroom, after giving a lecture, an instructor can only guess about students' understanding of subject matter. In contrast, when students work on problem solving modules they externalize their understanding of the concepts. Consequently, an instructor can identify understandings and misconceptions among the students.

Problems in any domain are typically multifaceted, involving several concepts simultaneously. One appreciates, therefore, that problem solving relies on knowing when a concept is appropriate, implementing that concept, carrying out an analysis and interpreting the result (Steif, 2003). However, the questions for the problem solving exercises need not be very difficult. Students should not feel having inadequate knowledge when attempting to solve the problem. There are paths, which takes students towards the success and give feeling of accomplishment. It is, therefore, the responsibility of a teacher to make such a lesson plan which could teach students how to solve a problem by implementing a concept. The fundamental purpose of written exercises in physics is to illustrate a principle working behind the question so that a student could understand the principles in that domain. Since the ability to solve written exercises involves application of concepts and procedure, surely one would hope that improved problem-solving ability translates into better understanding of concepts and vice-versa (Mazur, 1997; Steif, 2003; Svenson et al., 1983). This conceptual understanding empowers students to address their misconceptions. Emphasis was given to prepare such written exercises for this study that measures students' ability to identify a number of concepts and interrelationships among them.

The strategies students use while problem solving determine not only their knowledge and understanding of a particular concept but also what is learned by the student during the

process of problem solving. This learning may impact further problem solving skills of a student and push it closer to an expert's problem solving technique. An expert and a novice solve problems differently. Simon and Simon (1978) in explaining the distinction between novice and expert physics problem solvers suggest that novices solve their problems using means-ends analysis. Their results of an experiment show that novices generated solutions by choosing an equation containing the goal and then working backward toward the problem by choosing another equation that might solve a part in preceding equation. Once such equations are selected, the solution was reversed to attain solution toward the goal. In contrast, according to Simon and Simon (1998), experts appeared to eliminate the initial backward-working technique and began by generating equations forward from the givens towards the goal. Experts solve their problems using their well-knit schema, which allows a construction of a solution in the memory first, and translation of that construction to solve a problem. Suitable equations for the solution of a problem are then generated from this schema. As the schema is based on the given problem, Simon and Simon argue that a working-forward strategy is used. Novices, on the other hand, have insufficient knowledge to construct an appropriate representation of the problem in their schema, cannot work forward from the givens and, therefore, use means-ends analysis to reach to a solution.

Cooper, Hanmer, and Cerbin (2006) argues that by using problem solving technique instructors are able to give critical feedback to students during the learning process, which supports the development of their understanding. This iterative process of student problem solving followed by formative feedback by teachers develops a deeper conceptual understanding of difficult concepts. White (1993) argues that concept-oriented written exercises as an instructional strategy enable students to carry out causal analyses of physical phenomena, rather than algebraic constraint analyses. She further argues that through concept-oriented written

exercises students acquire powerful conceptual models of domain phenomena that enable prediction and explanation. After acquisition of such knowledge, students overcome their misconceptions and foster an understanding of physics and scientific inquiry. Examples of such exercises are given in Chapter 2. Each question in the exercise focuses on a single concept in isolation or if a question includes a group of concepts then it focuses on the concepts and their interrelationship. These concept-oriented written exercises require students to compare elements of their analysis of concepts with the scientific analysis, and to identify similarities and differences. The conceptual confrontation enables students to become aware of their existing notions and of the need to reconcile them with the scientific concepts and principles of concepts that are to be learned. Using such exercises as study guides automatically places a premium on thinking and minimizes the importance of memorization (McIntire, 1945). The student can be expected to find the interrelationships among critical concepts and apply the proper procedure to solve the exercises.

(c) Multimedia instruction

Multimedia is defined here as pedagogical content that uses a combination of different media forms. Multimedia includes any combination of text, graph, audio, still images, animation, and video. Examples of multimedia instruction include giving students an animation (i.e., combination of graphics and audio) around a concept being taught, playing an educational video (i.e., combination of visual effects and audio), or a PowerPoint presentation (i.e., combination of text, graph, and still images). Multimedia learning environments have the potential to significantly improve student learning compared to single media (Mayer & Moreno, 2002) because students learn more deeply when they build connections between a verbal representation and a multimedia representation of the same teaching material. This cognitive process of

integration is an important way to enhance students' understanding.

Mayer (2008) summarized the cognitive theory of multimedia learning in Figure 1.3. This figure also represents Mayer's framework for explaining how multimedia learning works. The boxes in the figure represent human memory stores whereas the arrows represent cognitive processes. Starting from the left of Figure 1.3, a learner receives words and pictures when a teacher uses multimedia instruction in a classroom. This multimedia instruction can be by video movies, interactive games, PowerPoint presentation or a textbook lesson having variety of media activities. In the second box of sensory memory, spoken words impact learner's ears whereas pictures and printed words impact on the eyes of a learner. The third box represents working memory of a learner and is divided into two sub-boxes. The left portion of the box represents that a learner selects a portion of sound and some images for further processing in his/her memory. This portion of the memory of a learner may interconvert sound and images depending of the utility a learner sees in that inter-conversion. In the right portion of the working memory box a learner organizes some preferred sounds into verbal model and some preferred images into pictorial model. In the last box which represents long-term memory, a learner can activate prior knowledge to integrate this new knowledge gain through verbal and pictorial models. At this final stage a learner also stores resulting new knowledge in long-term memory.

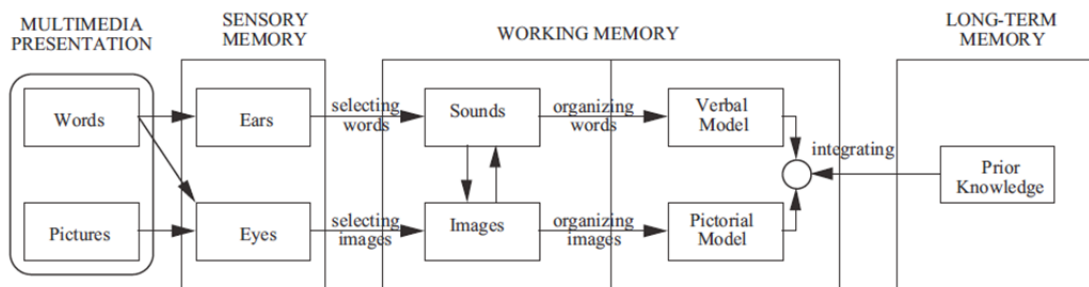


Figure 1.3. Cognitive Theory of Multimedia Learning (Mayer, 2008).

Multimedia is potentially useful in many situations. In a physics classroom, oral and/or written instruction including feedback given to a student may not be sufficient for changing students' misconceptions (diSessa, 1996; Hake, 1998). Multimedia contents can effectively simulate the real context of a situation, making it easy to understand. Creating of such an activity is challenging though, but once such an activity is prepared, it easily challenges misconceptions a student has. In a case study of two students, Roschelle (1992) analyzed students' conceptual change while working collaboratively with a Newtonian mechanics simulation. The researcher found that working collaboratively with different media developed a scientifically accurate understanding of acceleration in the two students. Engaged learning by multimedia instruction produces more acquisition of knowledge and understanding for addressing misconceptions and developing new ones (Farr, Ownbey, Branson, Cao, & Starr, 2005) because students learn better from words and pictures combined than from words alone (Mayer, 2008). Multimedia representation may provide the illusion of three-dimension to the students who are involved in virtual simulations. The three-dimensional simulations immerse the students in an artificial environment where they can move objects, observe phenomena, modify the variables of a system under observation, and so on (Ramat & Preux, 2003; Stanny, 2002). The active role of the students in such an environment motivates them to address their misconceptions and rebuild their new conceptions according to the firm scientific knowledge. Several studies have focused on the use of multimedia during lecture in a large classroom. Rossi (1995) observes that one problem teachers most frequently encounter is to continue to motivate students to seek in-depth knowledge. Kinzie and Sullivan (1989) suggest that when multimedia is used in a classroom, it assists students to seek in-depth knowledge and continues to keep them motivated. Sometimes, teachers need to show a big instrument (like a cyclotron or betatron) or a physical phenomenon

(like lighting effect or cyclone) to their students to address their misconceptions. Multimedia is an acceptable alternative, as we cannot bring big instruments like a cyclotron into the classroom.

Conceptual Framework of the Study

The primary purpose for pathfinder networks is to represent the knowledge structure of students. This purpose of pathfinder networks provides the basis of a conceptual framework to address three practical issues: (1) identifying the type of misconceptions among students, (2) giving remedial instruction to students based on their misconceptions shown by pathfinder networks, and (3) determining which specific type of remedial instruction (reflection, written exercises, and multimedia instruction), based on pathfinder network assessment, best improves the conceptual understanding of students. The conceptual framework of the study is shown in Figure 1.4. This conceptual framework illustrates the coherence and alignment of the concepts of misconceptions, pathfinder networks and remedial instruction with a student's knowledge structure.

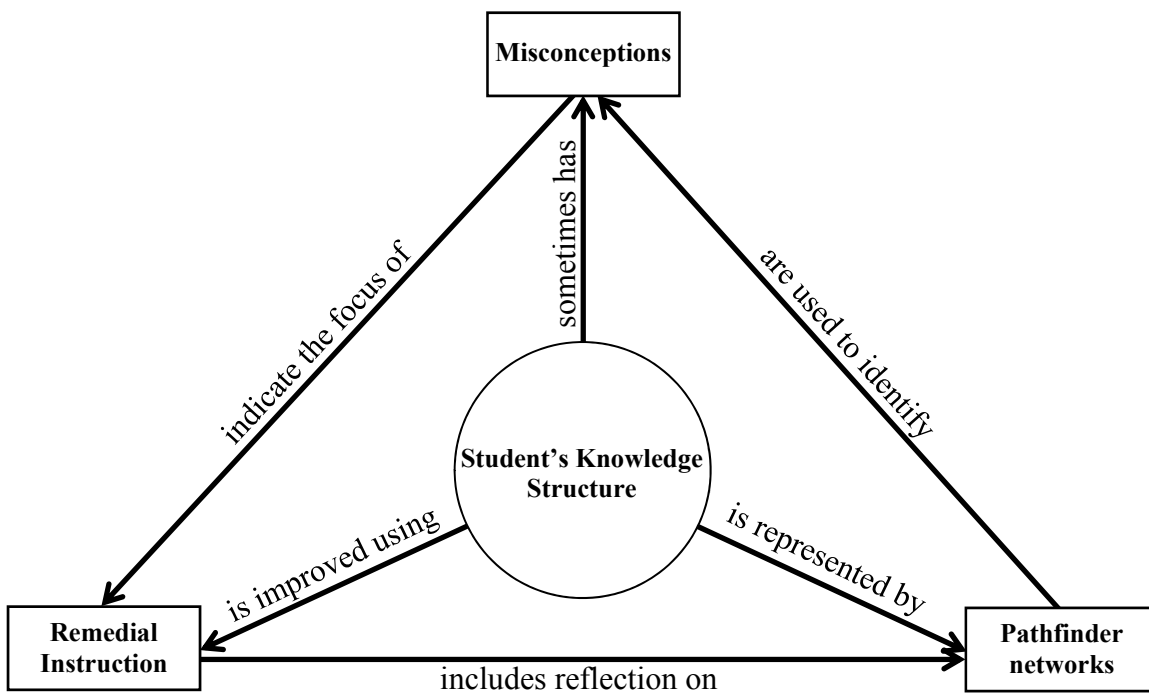


Figure 1.4. Conceptual framework of the study.

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 the conceptual framework should be 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 does have strong implications for the ways teachers see the teaching of the conceptual knowledge of physics. Moreover, pathfinder networks show stability in representation of structural knowledge under different elicitation conditions (Gammack, 1990). 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 taking an average of the ratings of more than one instructor, collected by the same technique addressing the same concepts, it is assumed that spurious relationship due to the experimental error may be removed by averaging. Thus one stable referent pathfinder network displaying a core organization of concepts in a domain could be established.

Research Questions

Research using pathfinder networks continues to proliferate in the measurement of conceptual knowledge within a wide range of disciplines and domains of inquiry. Many researchers make claims about applications of pathfinder networks in evaluation practices. Over the past twenty years, research of this category was done in abundance (e.g., Azzarello, 2007; Goldsmith & Johnson, 1990; Goldsmith, Johnson, & Acton, 1991; Kudikyala, 2004; Sarwar, 2011; Schvaneveldt & Durso, 1981; Trumpower & Sarwar, 2010; Trumpower, Sharara, &

Goldsmith, 2010; Trumppower, 2010). While variations in approach have provided a wide range of pathfinder networks applications, the use of pathfinder networks to measure comparative effectiveness of different type of classroom instruction has not been considered. Using the quantitative research approach, the study used PFnets to help develop and focus the remedial instruction, as well as measured the effectiveness of three types of remedial instructions as the central research question. Using the misconceptions shown by students' PFnets, three types of instructions were given to the students about their misconceptions. PFnets of each student was investigated around a particular concept. For this investigation, the study used a *treatment concept* and a *control concept* design. Treatment concept is the concept in the referent network about which three types of instructions were given to the students during three intervention stages. Control concept is the concept which is far away or least related to the treatment concept in the referent network and hence gets the least effect of the interventions. The main goal of the study is to explore which specific type of instruction best improves the conceptual understanding of the participants. Specifically, the study is guided by the following set of questions:

1. What effects do three types of remedial instructions (reflection, written exercises, and multimedia instruction), based on a student's unique knowledge structure, have on a treatment concept (or node) in his or her knowledge structure?
2. How does remedial instruction affect other non-targeted concepts in the student's knowledge structure?

The first research question involves the ability of creating effective individualized remedial instruction based on PFnet identified misconceptions. One type of instruction might be more effective as compared to the other two types of instruction. Therefore, for that particular instruction, there would be a greater increase in the similarity indices about the treatment

concepts in the pathfinder networks of the students from pre- to post-intervention phase as compared to the other two types of instructions. A secondary (exploratory) question, then, involves which out of three types of remedial instructions (based on PFnet feedback) best improves the knowledge structure of the students around the treatment concept.

The second research question intends to check the improvement of similarity indices, if any, because of the intervention around non-targeted concepts in the students' PFnets. This research question will validate that if the instruction is given to students around a particular concept, then only similarity of students' PFnets around that particular concept should increase. There should not be appreciable improvement of similarity of students' PFnet around the non-targeted concepts as there was no intervention around those concepts.

It is assumed that by conceptualizing the mental models of students using pathfinder networks, and comparing them with a referent network, it is possible to identify misconceptions among students. Furthermore, the presence of a specific link in the students' PFnets is taken to be indicative of their conceptual knowledge about that specific concept. The pathfinder networks thus generated are expected to provide insights needed to identify ambiguous, duplicate and misunderstood concepts by the students. These misconceptions can be addressed by giving different types of instructions to students around that particular concept. I assume that the instruction 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) around that particular concept.

Individual Hypotheses

Hypothesis 1. Three types of instructions were given to the students about the treatment concepts at three different stages. Therefore, there will be a statistically significant increase in the similarity indices about the treatment concepts in the pathfinder networks of the students from pre- to post-intervention phase.

Hypothesis 2. Three types of instructions were given to the students only about the treatment concepts and not about other concepts included in their networks. Therefore, there will not be a statistically significant difference in the similarity indices of other concepts (i.e., control concepts) not related directly to the treatment concepts in the pathfinder networks of the students from pre- to post-intervention phases.

Hypothesis 3. Although all the three types of instructions will be effective in improving students' domain knowledge, one type might be more effective as compared to the other two. Therefore, for that particular instruction, there will be a greater increase in the similarity indices about the treatment concepts in the pathfinder networks of the students from pre- to post-intervention phase as compared to the other two types of instructions. However, given that all three types of instruction are intended to help students understand conceptual relationships, the researcher does not make a clear hypothesis regarding the more effective type of instruction.

CHAPTER 2: METHODOLOGY AND DATA COLLECTION

The purpose of this study is to examine the effectiveness of three types of remedial instruction (reflections, written exercises, and multimedia instruction) as an intervention through the changes in students' similarity indices of PFnets from pre- to post-intervention. The students were divided into six sections, with each of the sections receiving three different types of interventions, one comprised of reflections, one comprised of written exercises, and one comprised of multimedia instruction. There were a total of six different orders in which the three types of interventions were assigned to the “motion”, “work, energy & power”, and “wave motion & nature of light” units, with each section randomly assigned to one of these six orders. As such, the order of units was fixed, but the order of intervention types was completely counterbalanced. An example of one such order is shown in Figure 2.1. The similarity index of the PFnets of each student with the referent PFnet around a particular concept was calculated before and after their reflections, before and after giving them written exercises, and before and after giving them multimedia instruction. The changes in students' similarity indices from pre- to post-intervention were taken as an indication of the effectiveness of each type of intervention.

Table 2.1 shows the order in which the three types of interventions were implemented (i.e., the order in which the three types of remedial instructions were given to the students) in the six sections. Each row in the table reflects one of the six sections. Therefore, a quasi-experimental design was employed such that sections were randomly assigned to one of the six orders but within a section order of three types of instructions was not randomized. In each of the interventions, different sets of concepts from three units (i.e., “motion”, “work, energy & power” and “wave motion & nature of light”) were used to collect the raw proximity data through using a questionnaire.

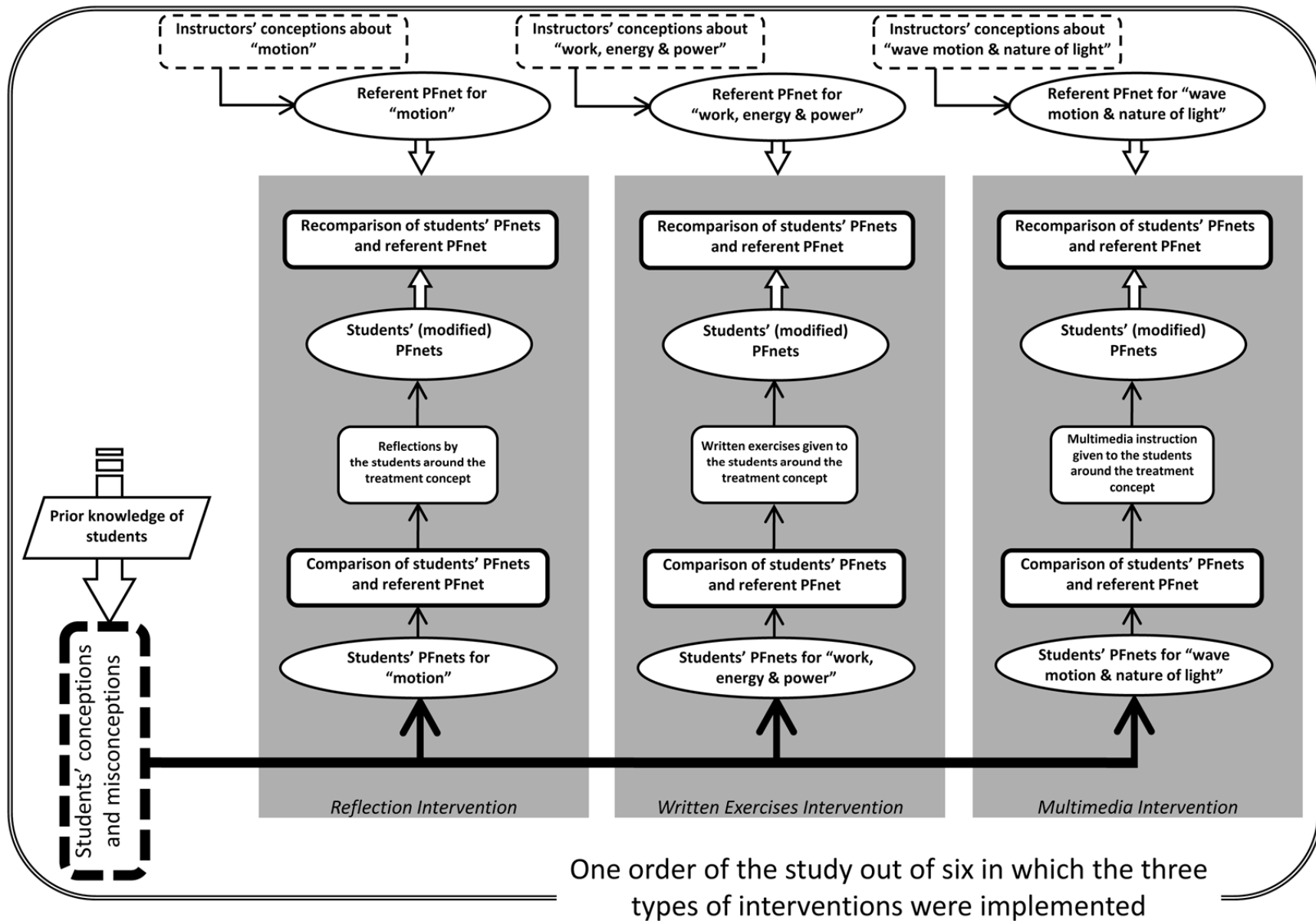


Figure 2.1. The design of this study.

Table 2.1

The Layout of the Study

202 Participants	Concepts from Motion Unit			Concepts from Work, Energy & Power Unit			Concepts from Wave Motion & Nature of Light Unit		
	Pre-relatedness ratings	Reflection as intervention	Post-relatedness ratings	Pre-relatedness ratings	Written exercises as intervention	Post-relatedness ratings	Pre-relatedness ratings	Multimedia instruction as intervention	Post-relatedness ratings
Section 1 22 Participants (Order 1)	Pre-relatedness ratings	Reflection as intervention	Post-relatedness ratings	Pre-relatedness ratings	Written exercises as intervention	Post-relatedness ratings	Pre-relatedness ratings	Multimedia instruction as intervention	Post-relatedness ratings
Section 2 31 Participants (Order 2)	Pre-relatedness ratings	Multimedia instruction as intervention	Post-relatedness ratings	Pre-relatedness ratings	Reflection as intervention	Post-relatedness ratings	Pre-relatedness ratings	Written exercises as intervention	Post-relatedness ratings
Section 3 25 Participants (Order 3)	Pre-relatedness ratings	Written exercises as intervention	Post-relatedness ratings	Pre-relatedness ratings	Multimedia instruction as intervention	Post-relatedness ratings	Pre-relatedness ratings	Reflection as intervention	Post-relatedness ratings
Section 4 52 Participants (Order 4)	Pre-relatedness ratings	Reflection as intervention	Post-relatedness ratings	Pre-relatedness ratings	Multimedia instruction as intervention	Post-relatedness ratings	Pre-relatedness ratings	Written exercises as intervention	Post-relatedness ratings
Section 5 44 Participants (Order 5)	Pre-relatedness ratings	Written exercises as intervention	Post-relatedness ratings	Pre-relatedness ratings	Reflection as intervention	Post-relatedness ratings	Pre-relatedness ratings	Multimedia instruction as intervention	Post-relatedness ratings
Section 6 28 Participants (Order 6)	Pre-relatedness ratings	Multimedia instruction as intervention	Post-relatedness ratings	Pre-relatedness ratings	Written exercises as intervention	Post-relatedness ratings	Pre-relatedness ratings	Reflection as intervention	Post-relatedness ratings

Participants

The participants of this research were nine physics instructors who have each had more than ten years of experience of teaching physics and 202 students of six sections taking a credit course in physics at Grade 11. The experiment was conducted at a college of Karachi, Pakistan. About two months before approaching students, the instructors were approached and asked if they would like to participate in the research project. Instructors were given a letter of information included as Appendix A and the recruitment text included as Appendix B. After giving them information about the study, the teachers were given a consent form included as Appendix C. All nine instructors agreed to participate in the study by signing the consent form.

Following the instructors' participation and analysis of data collected from them (described below), the students were approached and asked if they would like to participate in the research project. The copies of the information letter, recruitment text (included as Appendix D), the consent form for parents (included as Appendix E) and the assent form for students (included as Appendix F) were distributed in the classrooms by the researcher. The students were asked to sign the assent form and to bring back the consent forms signed by their parents in two days at the beginning of the first session of the study. Out of the total 202 students, 46 (i.e., 25 male students and 21 female students) were absent in one or more session, 4 (i.e., 3 male and 1 female) gave no response (blank) or multiple responses on 5 or more ratings in any one of the six questionnaires, and 19 (i.e., 15 male and 4 female students) were excluded due to unacceptably low reliability in their ratings (described in chapter 3), leaving a total of 133 student participants (83 male and 50 female) for analysis. The excluded students were spread evenly across the various intervention groups.

Implementation Procedure for Instructors

To attain a referent pathfinder network, nine physics instructors were recruited during

December, 2009. In consultation with these instructors, three sets of concepts, one set each from the units on “motion”, “work, energy & power” and “wave motion & nature of light”, were selected from the grade 11 physics textbook (see Appendices G-I). For this purpose single concepts, and not elaborated concept statements, were chosen. The criteria used for concept selection was:

- The concept must be covered in the course;
- The concept must be important for understanding the domain of physics;
- The concept must be representative of a wide range of physics topics (Azzarello, 2007).

The process of consultation with the physics instructors produced three final sets of 11 concepts from each unit as listed below.

Main concepts from “motion” unit

- | | | |
|-----------------|-----------------|-------------|
| 1. Distance | 5. Velocity | 9. Time |
| 2. Displacement | 6. Mass | 10. Inertia |
| 3. Force | 7. Acceleration | 11. Tension |
| 4. Gravity | 8. Momentum | |

Main concepts from “work, energy & power” unit

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

Main concepts from “wave motion & nature of light” unit

- | | | |
|----------------|-----------------|----------------------------------|
| 1. Wavelength | 5. Intensity | 9. Transverse wave |
| 2. Frequency | 6. Interference | 10. Longitudinal wave |
| 3. Time period | 7. Diffraction | 11. SHM (simple harmonic motion) |
| 4. Amplitude | 8. Polarization | |

The instrument for data collection was a rating scale from 1 (*completely unrelated*) to 5 (*highly related*). The instructors used this numeric rating scale for pairwise comparison of the concepts within each unit, given to them in a questionnaire (included as Appendices G-I). Each pair of the concepts was presented in one row in a random order and the instructors were asked to rate the strength of relationship between each pair. All pairwise combinations of 11 concepts [$(11^2 - 11)/2 = 55$ total pairs, where n is the total number of terms in the list] were created. Five pairwise comparisons were repeated at the end of the questionnaire to check the test-retest reliability of the ratings of the instructors (Trochim, 1989b). The left-right ordering of three of these five pairwise comparisons was changed during the repeat presentation. Therefore, the total number of concept pairs went up to 60. Some instructors were not familiar with this type of assessment technique. Therefore, a simple example of the procedure involving non-study related concepts was given to the instructors. For example,

Nest	Mammal	①	2	3	4	5	Circle "1" if you feel they are less related
Bat	Crow	1	2	③	4	5	
Chicken	Mammal	①	2	3	4	5	Circle "5" if you feel they are more related
Bat	Chicken	1	②	3	4	5	
Bird	Crow	1	2	3	4	⑤	

It was emphasized to the instructors that the whole range of rating values should be used while completing the ratings. The instructors completed and returned each of the three questionnaires, one from each unit, after about 15-20 minutes.

The Referent Pathfinder Network

The instructors' ratings were used to generate the referent networks, one for each unit. Sometimes it is possible that even instructors 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, it is always better to take an average of the ratings of more than one instructor to eliminate the possibility of having misconceptions in the referent network. Keeping this in view, expert ratings were taken from 9 instructors using the same three questionnaires which were used latter for the students from the units on “motion”, “work, energy & power” and “wave motion & nature of light” and the same rating scale (1 to 5). By averaging the relatedness ratings across the instructors and constructing a referent pathfinder network, it is assumed that spurious relationship due to any misconception, experimental error may be removed by averaging. Thus one stable referent pathfinder network displaying a core organization of concepts in a domain could be established.

To check test-retest reliability of the instructors’ ratings, Pearson correlation coefficients r were calculated from paired scores for the five comparisons which first appeared in the questionnaire and then repeated at the end for each participant instructor’s ratings. The study indicated significant consistency in the instructors’ ratings. Table 2.2 shows instructors’ Pearson correlation coefficients of five ratings, which appeared twice in the questionnaire, and its mean value around the units on “motion”, “work, energy & power” and “wave motion & nature of light”.

Table 2.2

Magnitude of Pearson Correlation Coefficients of the Instructors Calculated from Paired Scores for the Five Comparisons

	Unit on “motion”	Unit on “work, energy & power”	Unit on “wave motion & nature of light”	Overall mean Pearson Correlation Coefficient
Instructor 1	0.94	0.97	0.87	0.93
Instructor 2	0.95	0.95	1.00	0.97
Instructor 3	1.00	0.79	0.81	0.87
Instructor 4	0.85	0.81	0.75	0.80
Instructor 5	0.88	0.93	0.46	0.76
Instructor 6	0.95	0.94	0.70	0.86
Instructor 7	0.77	0.91	1.00	0.89
Instructor 8	0.81	0.95	0.89	0.88
Instructor 9	0.58	0.87	0.90	0.78
Mean	0.86	0.90	0.82	0.86

The mean Pearson correlation coefficient of all the units was above 0.70, which represents a very strong relationship. The overall mean Pearson correlation coefficient was 0.86. These correlation coefficient values show that instructors’ ratings were very reliable.

The Pearson correlation coefficient of an instructor was also calculated with the ratings of other instructors to measure how similar ratings of the instructors are to each other before averaging to get referent network. This was done to make sure that no instructor was an outlier. Tables 2.3 to 2.5 show an instructor’s Pearson correlation coefficient calculated with the ratings of other instructors around the units on “motion”, “work, energy & power” and “wave motion & nature of light” respectively.

Table 2.3

Pearson Correlation Coefficients of an Instructor Calculated with the Ratings of other Instructors around “motion” Unit

	Instructor 1	Instructor 2	Instructor 3	Instructor 4	Instructor 5	Instructor 6	Instructor 7	Instructor 8	Instructor 9
Instructor 1		0.84	0.77	0.76	0.47	0.79	0.71	0.80	0.54
Instructor 2	0.84		0.83	0.77	0.42	0.77	0.77	0.76	0.55
Instructor 3	0.77	0.83		0.81	0.45	0.83	0.80	0.73	0.53
Instructor 4	0.76	0.77	0.81		0.47	0.81	0.82	0.76	0.34
Instructor 5	0.47	0.42	0.45	0.47		0.54	0.51	0.49	0.10
Instructor 6	0.79	0.77	0.83	0.81	0.54		0.75	0.82	0.51
Instructor 7	0.71	0.77	0.80	0.82	0.51	0.75		0.71	0.38
Instructor 8	0.80	0.76	0.73	0.76	0.49	0.82	0.71		0.49
Instructor 9	0.54	0.55	0.53	0.34	0.10	0.51	0.38	0.49	
Mean	0.71	0.72	0.72	0.69	0.43	0.73	0.68	0.70	0.43

Table 2.4

Pearson Correlation Coefficients of an Instructor Calculated with the Ratings of other Instructors around “work, energy & power” Unit

	Instructor 1	Instructor 2	Instructor 3	Instructor 4	Instructor 5	Instructor 6	Instructor 7	Instructor 8	Instructor 9
Instructor 1		0.86	0.43	0.80	0.84	0.77	0.88	0.78	0.44
Instructor 2	0.86		0.51	0.79	0.84	0.77	0.87	0.77	0.39
Instructor 3	0.43	0.51		0.46	0.57	0.51	0.48	0.60	0.22
Instructor 4	0.80	0.79	0.46		0.82	0.77	0.84	0.77	0.50
Instructor 5	0.84	0.84	0.57	0.82		0.79	0.89	0.81	0.41
Instructor 6	0.77	0.77	0.51	0.77	0.79		0.79	0.73	0.41
Instructor 7	0.88	0.87	0.48	0.84	0.89	0.79		0.78	0.45
Instructor 8	0.78	0.77	0.60	0.77	0.81	0.73	0.78		0.47
Instructor 9	0.44	0.39	0.22	0.50	0.41	0.41	0.45	0.47	
Mean	0.72	0.72	0.47	0.72	0.75	0.69	0.75	0.71	0.41

Table 2.5

Pearson Correlation Coefficients of an Instructor Calculated with the Ratings of other Instructors around “wave motion & nature of light” Unit

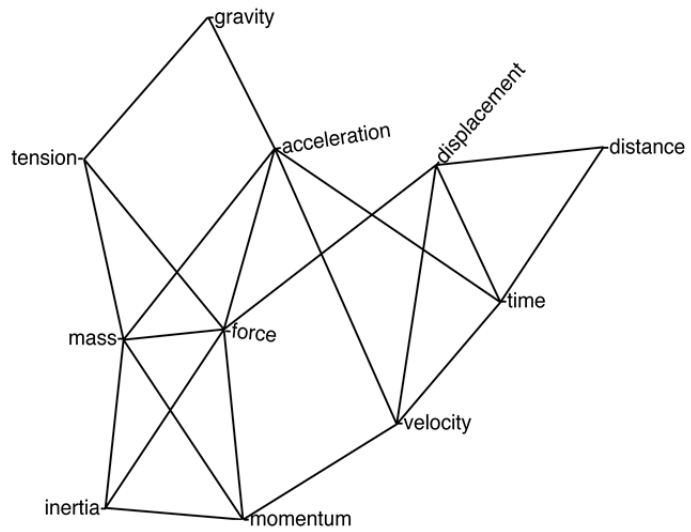
	Instructor 1	Instructor 2	Instructor 3	Instructor 4	Instructor 5	Instructor 6	Instructor 7	Instructor 8	Instructor 9
Instructor 1		0.65	0.70	0.65	0.45	0.39	0.75	0.60	0.29
Instructor 2	0.65		0.78	0.68	0.30	0.45	0.72	0.71	0.17
Instructor 3	0.70	0.78		0.63	0.56	0.37	0.69	0.54	0.35
Instructor 4	0.65	0.68	0.63		0.45	0.24	0.64	0.61	0.30
Instructor 5	0.45	0.30	0.56	0.45		-0.06	0.49	0.39	0.20
Instructor 6	0.39	0.45	0.37	0.24	-0.06		0.25	0.43	0.09
Instructor 7	0.75	0.72	0.69	0.64	0.49	0.25		0.66	0.37
Instructor 8	0.60	0.71	0.54	0.61	0.39	0.43	0.66		0.14
Instructor 9	0.29	0.17	0.35	0.30	0.20	0.09	0.37	0.14	
Mean	0.56	0.56	0.58	0.53	0.35	0.27	0.57	0.51	0.24

The cut-off value of 0.5 for Pearson correlation coefficients of the ratings of an instructor to the ratings of other instructors was taken for inclusion in generation of the referent networks for each unit. The 0.5 to 1.0 range of Pearson correlation coefficient represents moderate to high correlation (Morton, Hebel, & McCarter, 1996). Because of this cut-off value, instructors 5 and 9 were excluded from the averaged ratings used to create the referent network for the unit on “motion”. Similarly, instructors 3 and 9 were excluded from the averaged ratings used to create the referent network for the unit on “work, energy & power” and instructors 5, 6 and 9 were excluded from the averaged ratings used to create the referent network for the unit on “wave motion & nature of light”.

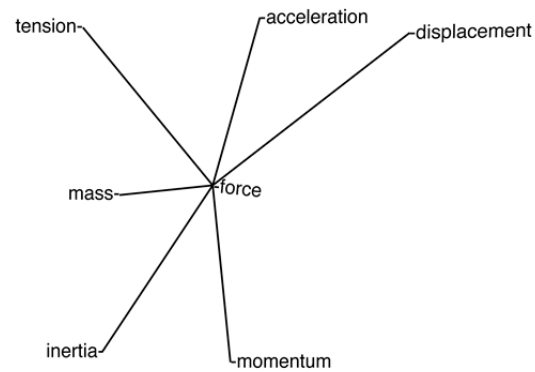
Before averaging the ratings to generate the referent networks, one final check of the validity of the knowledge elicitation process was conducted. The raw data from instructors were

entered into a Microsoft Excel 2010 spreadsheet and then transferred into individual proximity files to create a proximity matrix for each instructor. The data from these proximity matrixes were used as an input for KNOT software to generate each individual instructors' PFnet. KNOT software (Goldsmith & Davenport, 1990) reduces the raw proximity data to a least-weighted path that links all of the terms (Dearholt & Schvaneveldt, 1990). All of the participant instructors visually inspected their own pathfinder network and agreed that it was a valid representation of how they conceptualize relationships among the different concepts.

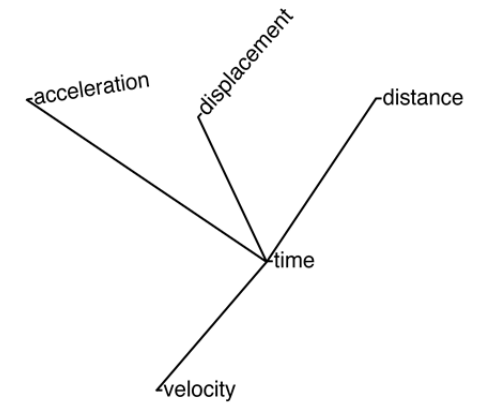
As the first step in data analysis, the researcher used Microsoft Excel 2010 to generate three sets, one for each unit, of averaged pairwise ratings of the instructors who met the above-described inclusion criteria. The instructors' averaged pairwise ratings were then used to construct three proximity matrixes. These proximity matrixes were used to generate the referent networks, one around each unit. These referent networks are shown in Figures 2.2 through 2.4. These three referent networks were further discussed with two instructors. One approved these referent networks without any change, but the second expert recommended changes in two referent networks. The second expert recommended that the referent network around the unit of "motion" should have a link between the concepts of force and time, and in the referent network around the unit of "wave motion & nature of light" links between the concepts SHM (simple harmonic motion) and amplitude and between the concepts SHM and frequency should be deleted. But the researcher decided that these two suggestions would not be employed, as these suggestions are relevant in the broader context of physics but are not very relevant in the context of the particular units of physics which were being considered in this study.



(a) The referent PFnet around the concepts of “motion”

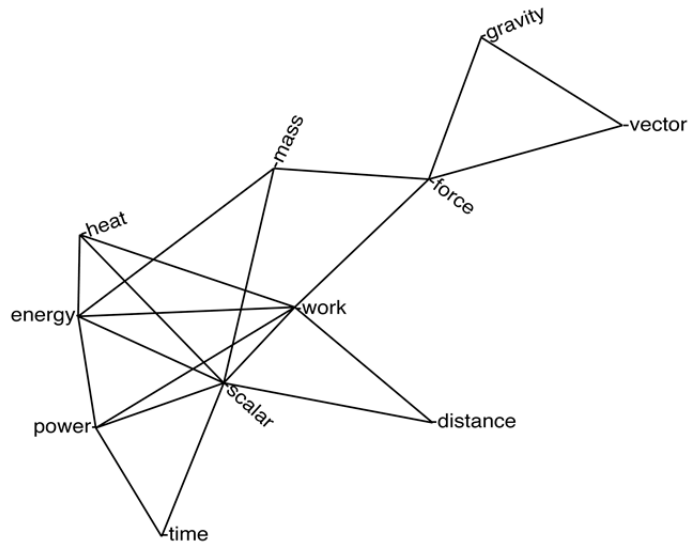


(b) Treatment concept of “force” was chosen from the referent PFnet

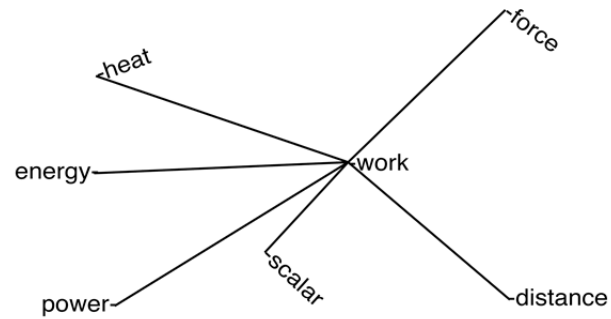


(c) Control concept of “time” was chosen from the referent PFnet

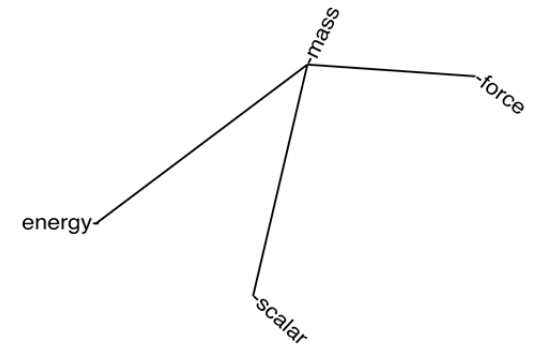
Figure 2.2



(a) The referent PFnet around the concepts of “work, energy & power”

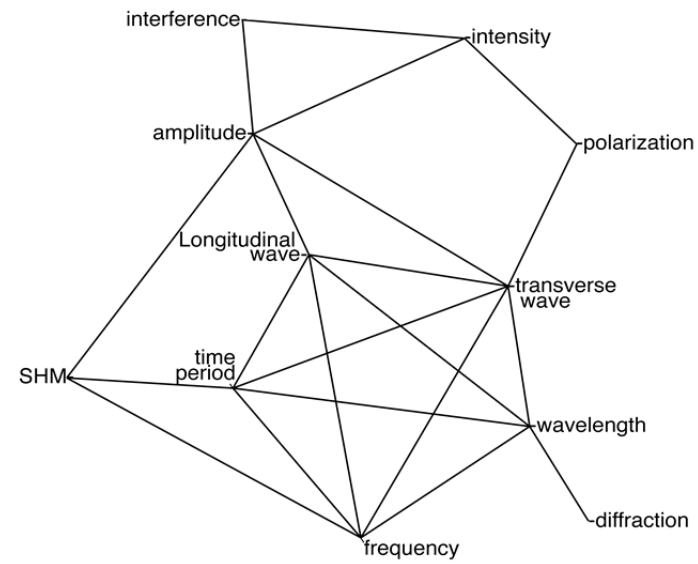


(b) Treatment concept of “work” was chosen from the referent PFnet

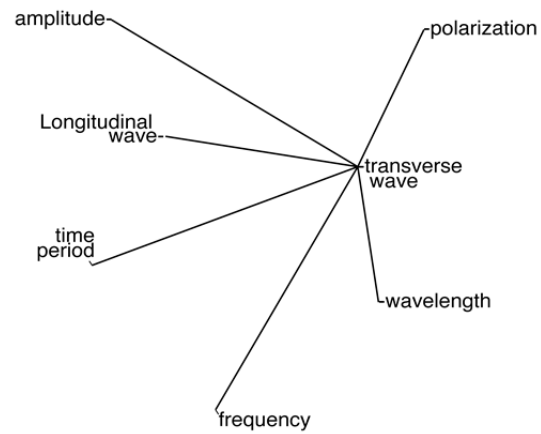


(c) Control concept of “mass” was chosen from the referent PFnet

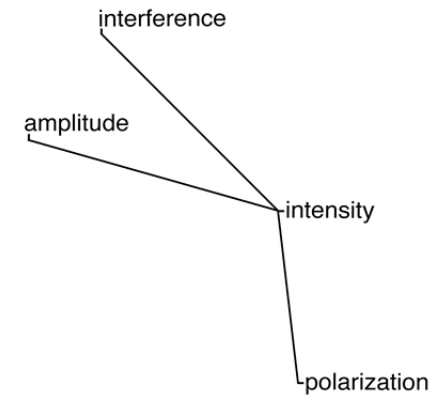
Figure 2.3



(a) The referent PFnet around the concepts of “wave motion & nature of light”



(b) Treatment concept of “transverse wave” was chosen from the referent PFnet



(c) Control concept of “intensity” was chosen from the referent PFnets

Figure 2.4

For this investigation, the study used a within-subjects *treatment concept, control concept* design for the analysis of data collected from the students. Therefore, after analyzing the referent networks, one treatment concept and one control concept was chosen from each of the three referent PFnets. The criteria for choosing the treatment concepts were that these concepts (i.e., the concepts of force, work and transverse wave) were linked to most of the concepts in the respective referent PFnets. The criteria for choosing the control concepts (i.e., the concepts of time, mass, and intensity) were that these concepts were least related to the treatment concept in the respective referent PFnet so that these concepts should get very little to no impact of interventions which are intended to modify the treatment concepts. No feedback was given to the students around these three control concepts during the intervention. Table 2.6 summarizes the *treatment concept* and the *control concept* chosen from each of the referent PFnets for analysis.

Table 2.6

Treatment Concepts and Control Concepts from the Three Physics Units

Unit	Treatment Concept	Control Concept
Motion	Force	Time
Work, energy & power	Work	Mass
Wave motion & nature of light	Transverse wave	Intensity

Implementation Procedure for Students

Student participants were approached during February-March, 2010, which was the second to last month of the school's session. At this stage it is generally assumed that students have learned most of their syllabus contents. The instructors of Grade 11 acknowledged that the students had covered the units on "motion", "work, energy & power" and "wave motion & nature of light". The students were given the same questionnaires (included as Appendices G-I)

that were given to the instructors and they used the same numeric scale for pairwise comparison of concepts. Exactly the same procedure which was first implemented for instructors was repeated to get the initial ratings of the students. A questionnaire for the relatedness rating task was given to the students for ratings from one of the three units. The students were asked to think about the physics domains of “motion”, “work, energy & power” or “wave motion & nature of light” (whichever type of questionnaire they have for the particular session) and to judge the relatedness of each pair of concepts by using the numeric scale from 1 to 5. The data was entered into the KNOT software to get students’ PFnets. Students’ PFnets were compared to the referent PFnet around the treatment concept. On the basis of misconceptions (i.e., missing links in the students’ PFnets with the treatment concept when compared with the referent network) found through this comparison, an intervention (e.g., reflection, written exercises, or multimedia instruction) was implemented in the students’ classroom. A different type of intervention was implemented in the students’ classrooms in each of the three phases. After implementing the intervention, data was collected again by administering a questionnaire using the same concepts as in the first questionnaire to generate students’ post-intervention PFnets. These post-intervention PFnets were compared again to the referent PFnets to find improvements, if any, in the students’ structural knowledge. The three types of interventions are discussed separately below. Each of the three types of interventions is further divided into three sub-types depending on the unit from which the treatment concept belonged. Therefore, there were nine distinct types of instructions in total and while giving these instructions to the students the order of intervention type was counterbalanced across sections.

Reflections as Intervention

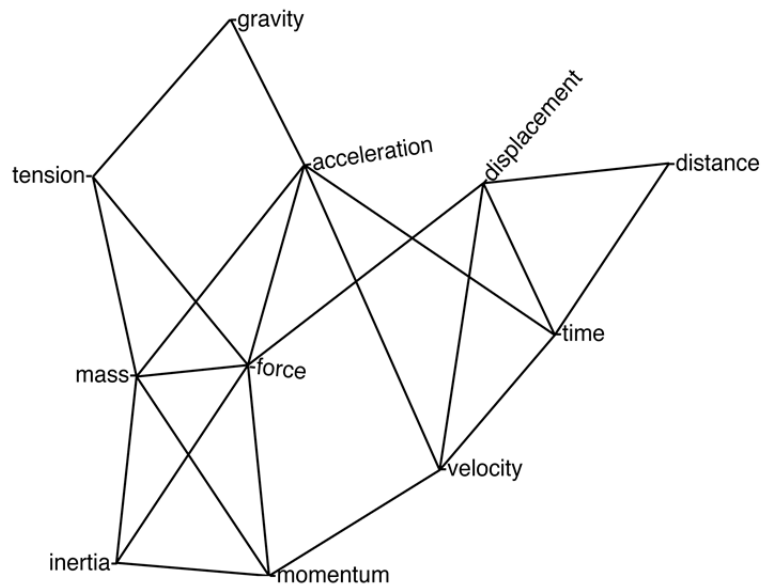
During the reflection intervention, students were given the referent PFnets and their own

pathfinder network. The students were asked to look at the referent PFnets and to add the missing links to their networks (with a dotted line) that the referent PFnets had but they did not, and to delete any additional but irrelevant links from their networks (by crossing them out with an “X”) that they had but the referent network did not. The students were encouraged to bring forward their own observation, previous experience and recent learning in understanding their misconceptions. They were also asked to determine and write their reflections on how the now linked concepts were relevant (or why the unlinked concepts were irrelevant). The students took about 20 to 30 minutes to write their reflections during college hours. Typically, every student wrote about half of a page of reflection on his/her misconceptions.

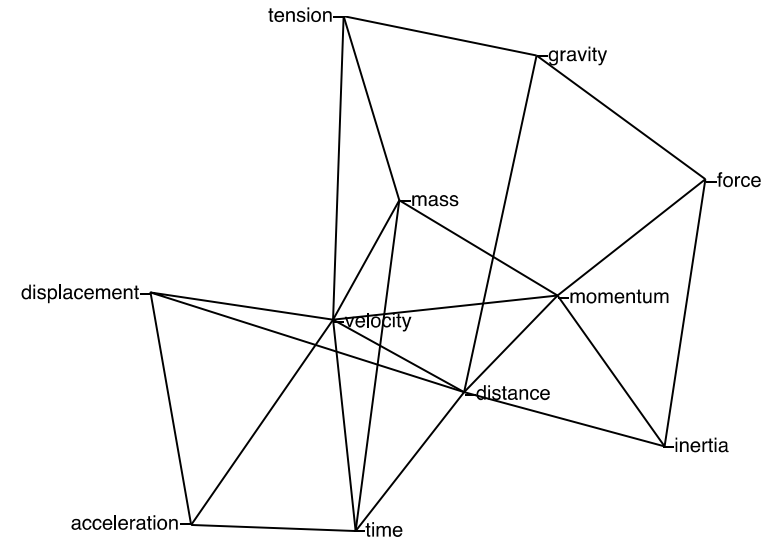
Reflection from the unit “motion” as Intervention. As shown in Figure 2.5(a), the referent PFnet shows that the concept of *force* is related to six other concepts, *i.e.*, *displacement*, *acceleration*, *tension*, *mass*, *inertia*, and *momentum*. Let us consider the *force* concept in the PFnet of the student-17, as shown in Figure 2.5(b). The student-17 links the concept of *force* with only *inertia* and *momentum* and misses the links of *force* with *displacement*, *acceleration*, *tension* and *mass* as compared to *force* concept in the referent PFnet. This student was given the following instruction for the reflection during intervention:

Your ratings indicate that you see the concept of “force” as being relatively strongly related to the concepts of “inertia” and “momentum”. Many expert scientists think that the concept of “force” is also strongly related to the concepts of “displacement”, “acceleration”, “tension” and “mass”. Can you think and reflect of ways in which “force” is strongly related to “displacement”, “acceleration”, “tension” and “mass”?

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



(a) The Referent PFnet around the concepts of “motion”.
Force concept was picked as a treatment concept.



(b) Student-17's PFnet around the concepts of “motion”.
Force concept was picked as a treatment concept to compare it with force concept in the referent PFnet.

Figure 2.5

Add the missing links to your Pathfinder network (with a dotted line) that the experts' averaged Pathfinder network has around the concept of "force" but you don't, and delete any additional and irrelevant links around the concept of "force" (by crossing them out with an "X") that you have but the experts' averaged Pathfinder network doesn't.

The reflection instructions from the units of "work, energy & power", and "wave motion & nature of light" are included as Appendix J and K respectively.

Written Exercises as Intervention

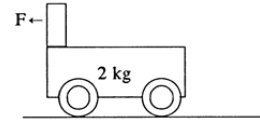
During the written exercises intervention, the written concept-oriented exercises to relinquish misconceptions about treatment concepts (i.e., concepts of force, work or transverse wave) were given to all the students. The students took about 20 to 30 minutes to complete these exercises during college hours. Only the researcher was present in the class during that time to answer any question about the exercises. Students were asked to solve some numerical problems and multiple-choice questions. All written exercises were designed specifically around the treatment concepts to provide considerable opportunities for the students to consider their own interpretations of the treatment concepts and their relationship with other concepts.

Written Exercises from the unit "motion" as Intervention. As shown in Figure 2.2(b), the referent PFnet shows that the concept of force is related to six other concepts, i.e., displacement, acceleration, tension, mass, inertia, and momentum. All students were given written exercises around all six of these related links (i.e., between force and displacement, acceleration, tension, mass, inertia, and momentum) during the intervention. The aim of giving written exercises around all the related links was to develop more knowledge around missing links of students and to enforce their existing links shown by their PFnets. The students were given the following written exercises during intervention:

(a) To develop more knowledge concerning force-acceleration link

1. The second law of motion establish the relation between

- (a) mass and motion
- (b) mass and velocity
- (c) velocity and acceleration
- (d) force and acceleration



2. A trolley of mass 2 kg is pulled along a smooth surface with a constant force F .

- (a) If the acceleration of the trolley is 4 m/s^2 , what is the magnitude of F ?
- (b) If the applied force is doubled, what will be the acceleration produced?

3. A force of 10 N acts on a mass of 2 kg. Calculate the acceleration which should be produced.

4. The net force acting on a body is zero. Which of the following quantities must also have zero magnitude for this body?

- (a) momentum
- (b) velocity
- (c) speed
- (d) acceleration

(b) To develop more knowledge concerning force-mass link

5. Newton's second law of motion helps in measuring

- (a) Force and velocity
- (b) Force and speed
- (c) Force and acceleration
- (d) None of the above answers

6. If force F is kept constant and mass m is doubled, the acceleration is

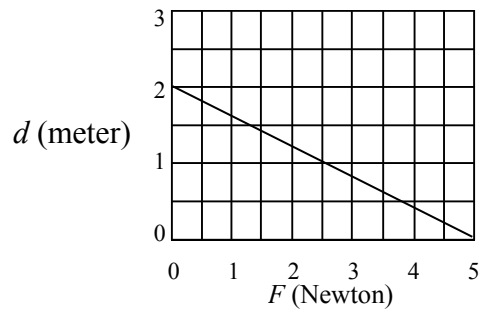
- (a) one fourth
- (b) halved
- (c) doubled
- (d) four time

7. A force of 200 N is acted on a mass of 50 kg, the motion of the object subsequently will be

- (a) motion at a constant speed of 0.25 m/s.
- (b) acceleration at a rate of 4 m/s^2 .
- (c) acceleration at a rate of 200 m/s^2 .
- (d) motion at a constant speed of 50 m/s.

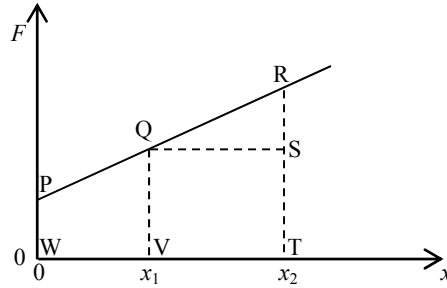
(c) To develop more knowledge concerning force-displacement missing link

8. The graph below shows the variation of displacement d with the force F applied on a cart.



The work done by the force in moving the cart through a distance of 2 m is

- (a) 10 J
 - (b) 7 J
 - (c) 5 J
 - (d) 2.5 J
9. The diagram below shows the variation of displacement x with the force F acting on an object in the direction of the displacement.



Which area represents the work done by the force when the displacement changes from x_1 to x_2 ?

- (a) QRS
- (b) WPRT
- (c) WPQV
- (d) VQRT

(d) To develop more knowledge concerning force-momentum link

10. If no unbalanced force acts on a particle or system, then

- (a) its momentum is a function of time.
- (b) its momentum is not conserved.
- (c) its momentum changes with distance.
- (d) its momentum is conserved.

11. Two balls, one light and the other heavy have equal momentum. Which of them has greater velocity?

- (a) The light ball.
- (b) The heavy ball.
- (c) Both have equal velocities.
- (d) Depends upon the direction of momentum.

12. A force of 50 N acts on a body for 10 s. What will be the momentum of the body?

- (a) 200 N-s
- (b) 500 N-s
- (c) 50 N-s
- (d) 5 N-s

13. When a body is accelerating, the resultant force acting on it is equal to the

- (a) change of momentum.
- (b) rate of change of momentum.
- (c) acceleration per unit of mass.
- (d) rate of change of kinetic energy.

(e) To develop more knowledge concerning force-inertia link

14. The physical quantity, which is the measure of inertia, is _____.

- (a) density
- (b) weight
- (c) force
- (d) mass

15. A and B are two objects with masses 75 kg and 100 kg respectively, then _____

- (a) both will have the same inertia.
- (b) B will have more inertia.
- (c) A will have more inertia.
- (d) both will have zero inertia.

16. Name the property of matter due to which a body continues in its state of rest or uniform motion unless an external force acts on it.

- (a) inertia

- (b) elasticity
- (c) viscosity
- (d) density

(f) To develop more knowledge concerning force-tension link

17. In a string, the tension force is always directed _____
- (a) along the length of the string.
 - (b) parallel to the length of the string.
 - (c) perpendicular to the length of the string.
 - (d) none of the above answers.
18. An elevator of mass 300 kg is hanging from a single cable. What is the tension in the cable if the elevator is moving at a constant velocity? Assume the value of $g = 10 \text{ m/s}^2$.
- (a) 3000 N
 - (b) 30000 N
 - (c) 1500 N
 - (d) 10 N
19. One of the following is not a force. Which one is it?
- (a) Gravitational pull
 - (b) Tension
 - (c) Mass
 - (d) Air resistance

The written exercises as in an intervention from the units of “work, energy & power”, and “wave motion & nature of light” is included as Appendix L and M respectively.

Multimedia Instructions as Intervention

During this intervention, multimedia concept-oriented instructions intended to relinquish misconceptions about treatment concepts (i.e., concepts of force, work or transverse wave) were given to all the students. While using multimedia contents, the study examined the use of demonstrations as an intervention. The researcher could have conducted the demonstrations himself, but the video clips are just more convenient and consistent in the demonstration. Thus, it is the content of the multimedia demonstrations rather than the medium in which they are presented that was tested as an intervention. The video clips were played in the classroom for about 20 to 30 minutes during college hours using a projector connected with a laptop computer. Only the researcher was present in the class during that time to answer any question about multimedia instructions. Students were asked to watch the video clips about the relationship of a concept with the treatment concept very carefully.

Multimedia Instruction from the unit “motion” as Intervention. As shown in Figure 2.2(b), the referent PFnet shows that the concept of force is related to six other concepts, i.e., displacement, acceleration, tension, mass, inertia, and momentum. All students were given multimedia instruction around all six of the related links (i.e., displacement, acceleration, tension, mass, inertia, and momentum) during intervention. The aim of giving multimedia instruction around all the related links was to develop more knowledge around missing links of students and to enforce their existing links shown by their PFnets. The students were given the following multimedia instruction during intervention. The multimedia instruction cannot be produced on a paper, therefore, only screenshots and the summary of the contents in the multimedia instruction is given here. The following paragraph after each multimedia instruction is a brief transcript about what was shown in the video clip.

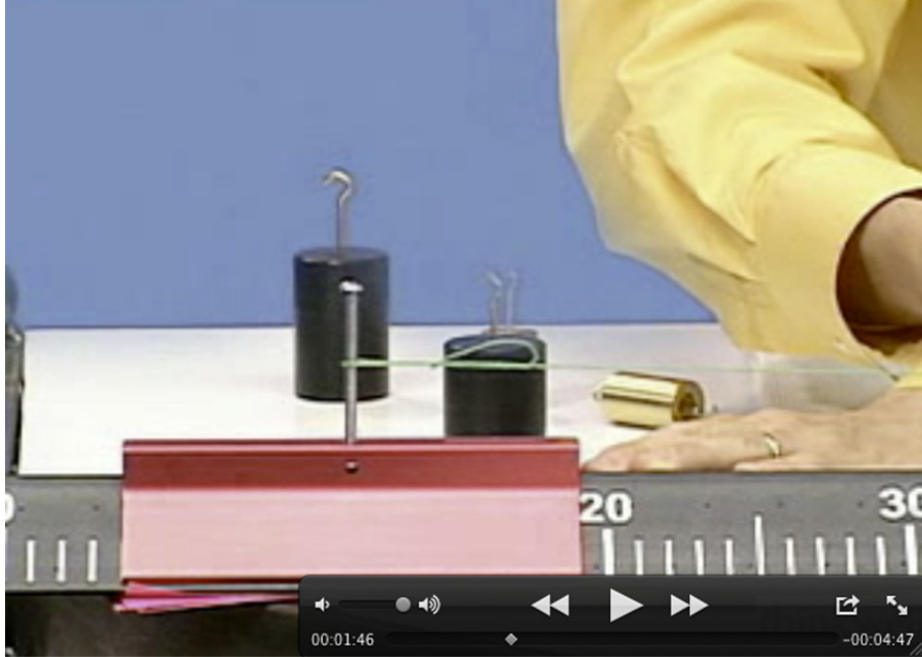


Figure 2.6. To develop more knowledge concerning force-acceleration link.

The video clip in Figure 2.6 (<http://www.thinkwell.com/student/product/physics>) showed students what force does when you apply it to an object. The demonstration was geared around a way of measuring force. The demonstrator showed that when a small force is applied on the object, nothing happens, because there are a lot of other forces acting on the object in addition to that applied by the demonstrator. The most important force is the force of friction between the object and the table. The demonstrator eliminated that force of friction by using ‘air track’. After that, the demonstrator took a string, hung some weight with it, and put it over a pulley, tying the string to the object. Thus, without friction, the demonstrator applied a constant force, and the object moved and accelerated with the time. The velocity of the object increased steadily which is the constant acceleration. The demonstrator later repeated the whole procedure by doubling the force and showed that the acceleration also doubles, proving that acceleration is proportional to the force. At the end, the demonstrator concluded that all of this is Newton’s second law $\vec{F} = m\vec{a}$, which tells us that when you apply a force to an object, the object will accelerate.



Figure 2.7. To develop more knowledge concerning force-mass link.

The video clip in Figure 2.7 (<http://www.thinkwell.com/student/product/physics>) showed students that when you increase the mass of an object, you require more force to move it. The demonstrator showed that when mass is doubled, the object will accelerate under the influence of the force; however the acceleration will be less as compared to body with a less mass. The acceleration depends on what the mass of an object is, i.e., $a \propto \frac{1}{m}$, and it goes inversely. From this relation, the demonstrator derived the equation $\vec{a} = \frac{\vec{F}}{m}$. The acceleration depends on nothing else except for the amount of force and mass of the body. Mass is measured in kilograms and acceleration in meter per second square. From these two units, the unit of force can be picked up and is called Newton. The demonstrator then rewrote the equation as $\vec{F} = m\vec{a}$ and observed it as Newton's second law, which, as aforementioned, tells us that when you apply a force on an object, the object will accelerate. Newton's second law explains that the reason that an object accelerates is because you push or pull on it and that it is quantitative. If you know the amount of force and the mass of the body, you can measure the acceleration.

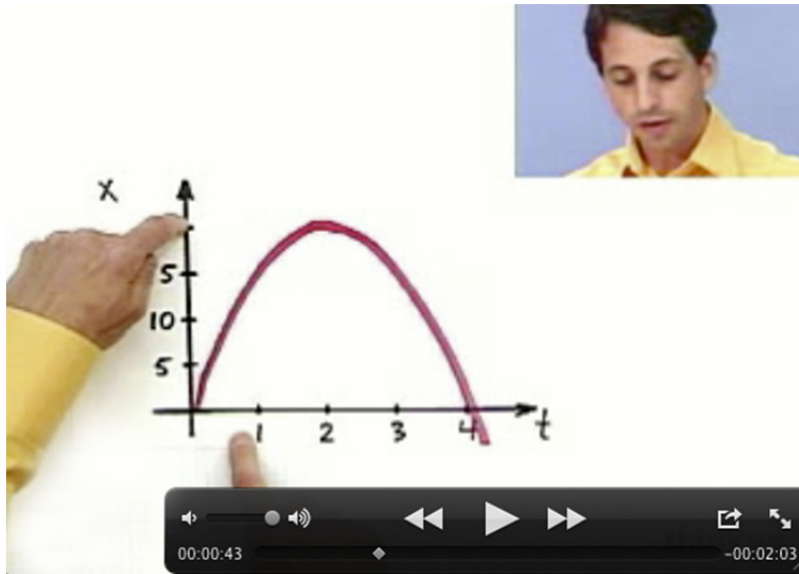


Figure 2.8. To develop more knowledge concerning force-displacement link.

The video clip in Figure 2.8 (<http://www.thinkwell.com/student/product/physics>) showed students that velocity is obviously not the same thing as position, but it is connected. Velocity tells you how the position of an object is changing with time. Similarly, acceleration is not the same thing as the velocity, but again, are connected. The connection between position, velocity and acceleration are very important. During the video, the demonstrator drew a graph relating the position (x) in accordance to the time (t) for a ball thrown up in the air. It starts up from ground level, goes higher and higher, comes to a stop, and heads back down again. The demonstrator further showed that when you talk about the velocity (v), you simply take the derivative of x , i.e., $= \frac{dx}{dt}$. The derivative of the curved graph will be a straight line. The demonstrator then talked about the connection between the two graphs. If you measure the slope of x versus t at any instant of time, it will tell you the velocity. The demonstrator goes one step further to show that acceleration is a derivative of velocity, i.e., $a = \frac{dv}{dt}$. If we take the slope of velocity graph, it will tell us the acceleration and the slope of that graph will be zero. From this acceleration, we can calculate the force by just multiplying it with the mass of a body.



Figure 2.9. To develop more knowledge concerning force-momentum link.

The video clip in Figure 2.9 (<http://www.thinkwell.com/student/product/physics>) defines momentum, which is given the symbol \vec{p} and is equal to mass times velocity ($m\vec{v}$). If you take a big object and toss it around, it has a large momentum. In the video clip, it was shown that if the object travelled between the demonstrator's hands, hitting the opposite ends of its path with speed, the demonstrator would, and did, feel difficulty in stopping the ball because of its large mass. The demonstrator asked if this difficulty was because of velocity. Certainly when a body with a large mass moves, it is difficult to stop it. But it is not just velocity, as shown when the demonstrator took a little object and tossed it around with even greater velocity. It was not difficult to stop this particular body as compared to the body with the larger mass. So the expression mass times velocity certainly seems to carry some physical insight with it. The demonstrator gave another hint as to why momentum is a useful physical quantity by thinking of Newton's second law. In the video, the demonstrator derived the equation $\vec{F} = m\vec{a} = m \frac{d\vec{v}}{dt} = \frac{d(m\vec{v})}{dt}$, where $m\vec{v}$ is the momentum, meaning that momentum is a property of an object; if you know the velocity and the mass, you know the momentum.



Figure 2.10. To develop more knowledge concerning force-inertia link.

The video clip in Figure 2.10 (http://www.youtube.com/watch?v=MxxLeFx3A_E) showed students that inertia means laziness—the tendency that things have to keep on doing what they are already doing. Big things are not always lazier than small things; it all depends on how much mass they have. This means that as the mass increases, so does the inertia. In the video clips, two balls of the same size but different masses are shown. It was shown that the ball with higher mass would be more difficult to throw because more mass means more inertia. The only way to overcome the inertia is to use force. At the end, the video clip takes the quantitative approach and shows two balls with masses of 1 kg and 2 kg. The video showed these two balls being thrown the same distance, however twice the force was required to throw the 2 kg ball than the 1 kg one. Therefore, if you double the mass, you double the force needed to make it move or to make it stop moving. In other words, if inertia is doubled, the force needed to overcome it must also be doubled.

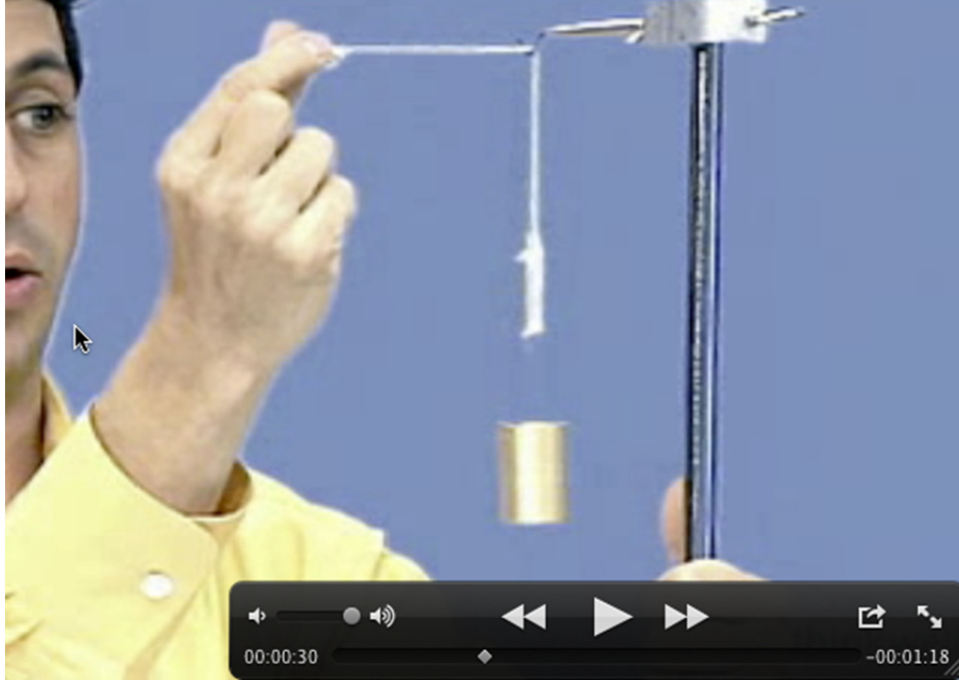


Figure 2.11. To develop more knowledge concerning force-tension link.

The video clip in Figure 2.11 (<http://www.thinkwell.com/student/product/physics>) showed students that if you take an object tied with a rope and lift it up, there would be tension created in the rope. This tension provides the upward force which holds the object up. On the other end of the rope, the object pulled down; therefore, demonstrator felt the tension from the two opposing forces. By wrapping the rope around the pulley, you can change the direction of the force on the two ends. The tension, the magnitude of the force, is the same at both ends but the direction is quite different. The portion of the string tied to the mass pulls downwards whereas the other end of the string held by hand pulls sideways. Later, as an example, the demonstrator proved that if an object is at rest, its weight ($W = mg$) and its tension (T) should be equal. The weight of the body acts downwards whereas the tension acts upwards. The tension in the string can be calculated using Newton's second law.

The multimedia instruction as in an intervention from the units of “work, energy &

power”, and “wave motion & nature of light” is included as Appendix N and O respectively.

Each intervention lasted for about 20 to 30 minutes. After the intervention was implemented using reflection, written exercises or multimedia instruction the student participants were asked to complete second ratings, using identical procedures and the same rating scale as first ratings before the intervention. The participants completed and returned the questionnaire after about 15-20 minutes (post-intervention ratings).

CHAPTER 3: DATA ANALYSIS AND RESULTS

The applicability of conclusions drawn from pathfinder networks requires some measures of validity and reliability. To address *validity* of conclusions drawn from the students' pathfinder networks, the similarity indices of "time", "mass" and "intensity" concepts (control concepts) from the units on "motion", "work, energy & power", and "wave motion & nature of light" respectively in the pathfinder networks of the students were also checked for improvement in addition to the similarity indices of "force", "work" and "transverse wave" concepts (treatment concepts) from the same units on "motion", "work, energy & power", and "wave motion & nature of light" respectively. The reliability of students' ratings was assessed by repeating five pairwise comparisons at the end of each questionnaire during both pre- and post-intervention ratings. Whereas the validity and reliability of instructors' pathfinder networks was already discussed in chapter 2, the validity of conclusions drawn from the students' PFnets and the reliability of their PFnets will be discussed in this chapter.

Reliability of the Students' Ratings

To check the reliability of the ratings across time, Pearson correlation coefficients r were calculated from paired scores for the five comparisons which first appeared in each questionnaire and then were repeated at the end of each questionnaire for each participant's ratings. (Trumpower, 2003). This was the same procedure, which was first adopted to calculate the consistency in the instructors' ratings in chapter 2 and was adopted again to check consistency in the students' ratings. The study found significant consistency in students' ratings. Table 3.1 shows the mean Pearson correlation coefficients of 152 students in pre- and post-intervention ratings.

Table 3.1

Mean Pearson Correlation Coefficients, r , of the Students Calculated from Paired Scores for the Five Comparisons

Intervention type	r
Reflections	
Pre-intervention	0.54
Post-intervention	0.63
Written Exercises	
Pre-intervention	0.48
Post-intervention	0.47
Multimedia Instruction	
Pre-intervention	0.48
Post-intervention	0.51
Average across all 6 questionnaires	0.52

Although the overall mean value of 0.52 for the Pearson correlation coefficients shows consistency among students' ratings, there were some variations among individual students' correlations. Further analysis led to the categorization of students according to their Pearson correlation coefficients. In Table 3.2, each row shows the number of participants who are in a certain range of the Pearson correlation coefficient. Ratings by students having poor average Pearson correlation coefficients ($-1 \leq r < 0.5$) across all six questionnaires were eliminated from data analysis (Cohen, 1992). Table 3.2 shows that out of 152 student participants, 133 were retained for further analysis.

Table 3.2

Number of Participants in a Certain Range of Pearson Correlation Coefficient Calculated from Paired Scores for the Five Comparisons

Ratings (pre- & post-intervention)	Magnitude of Pearson correlation coefficients (r) ^a			
	Strong	Moderate	Weak	Negligible
	$0.8 \leq r \leq 1$	$0.5 \leq r < 0.8$	$0.2 \leq r < 0.5$	$-1 \leq r < 0.2$
Reflections				
Pre-intervention	60	40	22	30
Post-intervention	73	42	23	14
Written Exercises				
Pre-intervention	54	41	26	31
Post-intervention	58	45	16	33
Multimedia Instruction				
Pre-intervention	54	41	26	31
Post-intervention	51	43	32	26
Average across all 6 questionnaires	16	117	6	13

^a Range of Pearson correlation in the table is adapted from Table X-I of Morton, Hebel, & McCarter (1996).

Data Entry for Students' Pathfinder Networks

The raw data from students were entered into a Microsoft Excel 2010 spreadsheet and data from each column of the spreadsheet was copied into individual proximity files to create a proximity matrix for each participant. The data from the proximity matrix was used as input for the KNOT software to generate individual students' PFnets.

Treatment of Students' Missing Data in their Ratings

Two common methods for dealing with missing data are either to exclude all data records where a participant gave no response (blank) or multiple responses for any variable value (list-wise deletion) or to substitute acceptable values for the missing items (Goldstein & Woodhouse,

1996). Where data items are missing completely at random, the list-wise deletion method produces unbiased estimates but may decrease the power of analysis by excluding a high proportion of records (Gibson & Olejnik, 2003). Therefore, a compromise procedure was adopted to deal with the no response (blank) or multiple responses instead of a single response on each row of rating data. The records of 4 students who left blank or gave multiple responses on 5 or more ratings in any one of the six questionnaires were list-wise deleted. Whereas, a rating of 3 (*neutral*) was entered for students who left blank or gave multiple responses on 4 or less ratings-in any of the six questionnaires. The rating of 3 was selected under the assumption that a neutral response best reflects the undecided response by the students for a particular rating.

Data Analysis

Two similarity indices around each treatment concept (i.e., the concept of force, work, and transverse wave) of students' and referent PFnets were calculated—one for pre-intervention and another for post-intervention. In the intervention phase of the experiment, reflections, written exercises, and multimedia instruction were given to the students, focusing on relationships with treatment concepts as indicated in the referent PFnets. This was done to verify the first hypothesis of the study, which says that the similarity index around treatment concepts in the pathfinder networks of the students would increase from pre- to post-intervention due to the intervention. To investigate further whether the increase in the similarity index in students' PFnets is due to the increase in the number of relevant links and/or decrease in the number of irrelevant links, the relevant and irrelevant links in the concept of force, work, and transverse wave in the students' PFnets were also compared to the number of relevant links in the force, work, and transverse wave concepts in the referent PFnet. In order to address issues of validity, concepts of time, mass, and intensity from the units of “motion”, “work, energy & power” and

“wave motion & nature of light” respectively were chosen for analysis as control concepts. This was done to verify the second hypothesis of the study (stated earlier in the chapter 1) about these control concepts which says that there will be a statistically non-significant difference between pre-intervention and post-intervention similarity indices of control concepts in the pathfinder networks of the students. To evaluate this hypothesis, time, mass and intensity concepts in a student’s PFnets were compared to the same concepts in the referent PFnets to calculate two similarity indices—one for pre-intervention and another for post-intervention. To further investigate the similarity index of control concepts, the numbers of relevant and irrelevant links in time, mass and intensity concepts in the students’ PFnets were also compared to the number of relevant links in time, mass and intensity concepts in the referent PFnet.

Analysis of Similarity Indices around Treatment and Control Concepts in Students’ PFnets

A 3 Type of Instruction (reflection, written exercises, multimedia instruction) \times 2 Type of Concept (treatment, control) \times 2 Time (pre-intervention, post-intervention) within-subjects analysis of variance (ANOVA) on mean similarity index was computed using Statistical Package for the Social Sciences (SPSS) version 19 for Windows. An alpha level of .05 was used to test for statistical significance in all analyses in this study. Table 3.3 shows descriptive statistics of the test.

Table 3.3

Mean Similarity Indices as a Function of type of Instruction (Reflections, Written Exercises, or Multimedia Instruction), Type of Concept (Treatment or Control), and Time (Pre-Intervention or Post-Intervention)

	Concept			
	Treatment		Control	
	Pre-intervention Mean (SD)	Post-intervention Mean (SD)	Pre-intervention Mean (SD)	Post-intervention Mean (SD)
Type of Instruction				
Reflections	.41 (.19)	.68 (.21)	.38 (.22)	.37 (.25)
Written exercises	.41 (.19)	.51 (.21)	.30 (.23)	.35 (.27)
Multimedia instruction	.37 (.18)	.62 (.23)	.30 (.22)	.39 (.28)

A three-way interaction was examined. The interaction among independent variables of type of instruction, type of concept, and time was significant with $F(1, 132) = 12.65; p = 0.00$. This three-way interaction can also be seen by comparing graphs in Figures 3.1 and 3.2. Figure 3.1 shows the two-way interaction between type of instruction and time for the treatment concepts whereas Figure 3.2 shows the corresponding two-way interaction for the control concepts. Therefore, simple two-way interactions of *type of instruction* \times *time* were examined separately for the treatment concepts and the control concepts. Results revealed that the *type of instruction* \times *time* interaction was significant with $F(1, 132) = 16.55, p = 0.00$ for the treatment concept and marginally significant for the control concept with $F(1, 132) = 3.04, p = 0.05$. Thus, pairwise comparisons of the similarity indices of the students' PFnets around the treatment and control concepts from pre- to post-intervention phase for each type of instruction were conducted. Given the exploratory nature of this analysis, no adjustment to a standard alpha level of 0.05 was made.

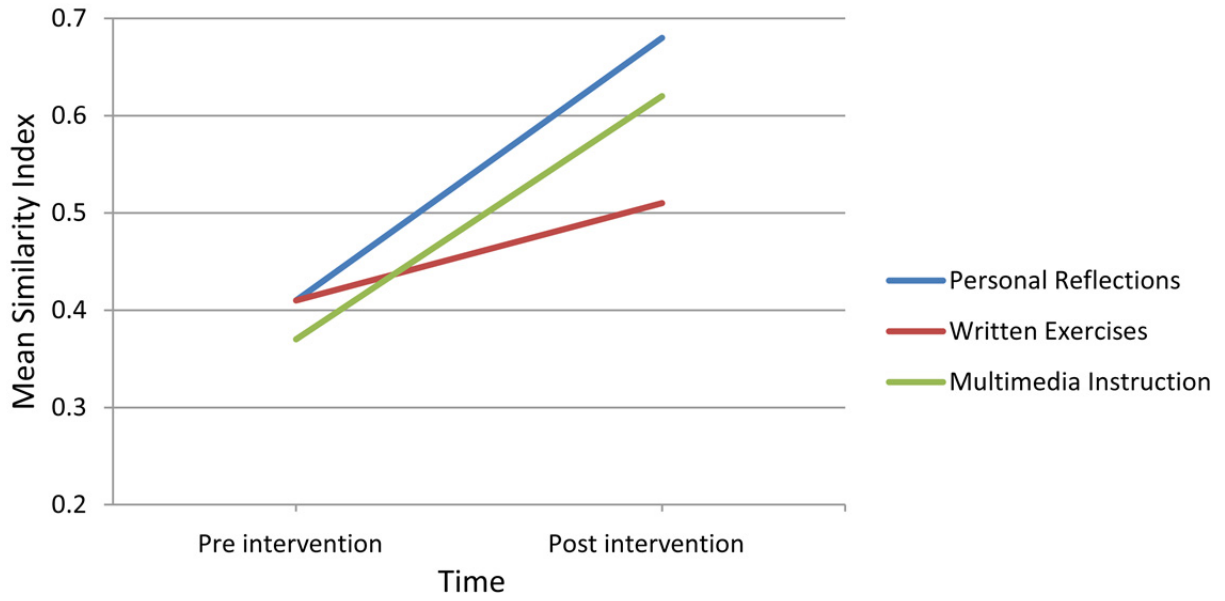


Figure 3.1. Two-way interaction of the treatment concepts when three types of instructions were given.

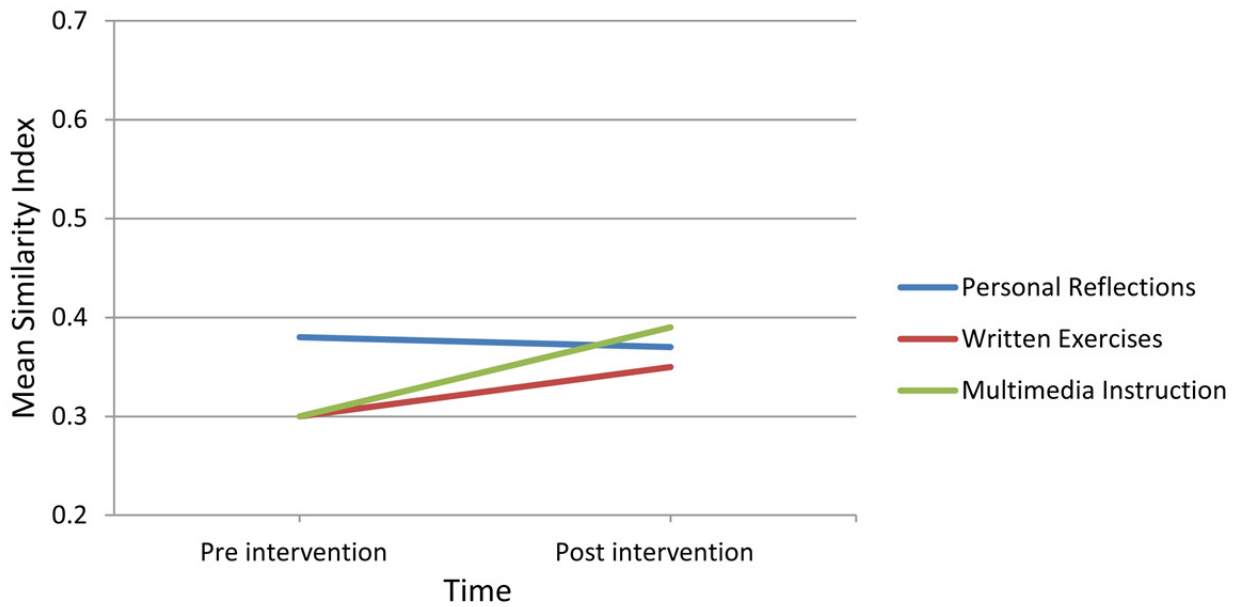


Figure 3.2. Two-way interaction of the control concepts when three types of instructions were given.

Pairwise Comparisons of the Similarity Indices around the Treatment Concepts

From the first pairwise comparison, pre-intervention and post-intervention similarity indices of students' PFnets around treatment concepts when reflections were used as an intervention yielded a significant difference among them, with $F(1, 132) = 136.65; p = 0.00$. The pre-intervention mean similarity index of the students was 0.41 ($SD = 0.19$) which increased to 0.68 ($SD = 0.21$) in the post-intervention ratings. This finding shows that the similarity of the students' PFnets with the referent PFnet around treatment concepts increased when reflections were used as intervention.

From the second pairwise comparison, pre-intervention and post-intervention similarity indices of students' PFnets around treatment concepts when written exercises were used as an intervention yielded a significant difference, with $F(1, 132) = 16.82; p = 0.00$. The pre-intervention mean similarity index of the students was 0.41 ($SD = 0.19$) which increased to 0.51 ($SD = 0.21$) in the post-intervention ratings. This finding shows that the similarity of the students' PFnets with the referent PFnet around treatment concepts increased when written exercises were used as intervention.

From the third pairwise comparison, pre-intervention and post-intervention similarity indices of students' PFnets around treatment concepts when multimedia instruction was used as an intervention yielded a significant difference, with $F(1, 132) = 100.20; p = 0.00$. The pre-intervention average similarity index of the students was 0.37 ($SD = 0.18$) which increased to 0.62 ($SD = 0.23$) in the post-intervention ratings. This finding shows that the similarity of the students' PFnets with the referent PFnet around treatment concepts increased when multimedia instruction was used as intervention. Further, the inspection of the means of similarity indices supports that reflections best improved the similarity indices about the treatment concept in the students'

pathfinder networks from pre- to post-intervention phase, followed by multimedia instruction and written exercises (hypothesis 3).

Pairwise Comparisons of the Similarity Indices around the Control Concepts

From the first pairwise comparison, pre-intervention and post-intervention similarity indices of students' PFnets around control concepts when reflections were used as an intervention yielded a non-significant difference among them, with $F(1, 132) = 0.06$; $p = 0.81$. The pre-intervention mean similarity index of the students was 0.38 ($SD = 0.22$) which very slightly decreased to 0.37 ($SD = 0.25$) in the post-intervention ratings. This finding shows that the similarity of the students' PFnets with the referent PFnet around control concepts did not change significantly when reflections were used as intervention (hypothesis 2).

From the second pairwise comparison, pre-intervention and post-intervention similarity indices of students' PFnets around control concepts when written exercises were used as an intervention again yielded a non-significant difference, with $F(1, 132) = 2.78$; $p = 0.10$. The pre-intervention mean similarity index of the students was 0.30 ($SD = 0.23$) which increased to 0.35 ($SD = 0.27$) in the post-intervention ratings. This finding shows that although the similarity of control concepts in the students' PFnets increased slightly with the referent PFnet around control concepts, it is statistically non-significant (hypothesis 2).

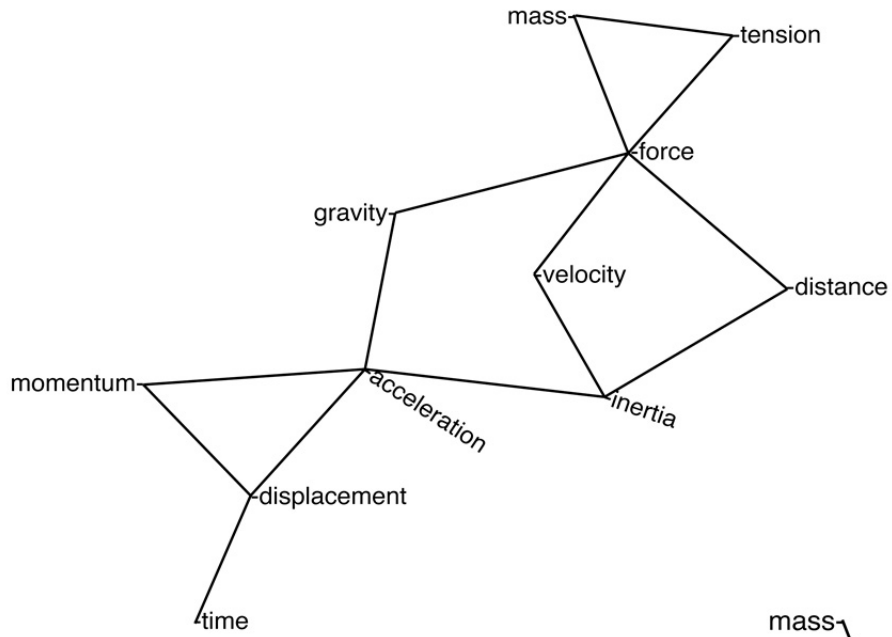
From the third pairwise comparison, pre-intervention and post-intervention similarity indices of students' PFnets around control concepts when multimedia instruction was used as an intervention yielded a significant difference, with $F(1, 132) = 8.87$; $p = 0.00$. The pre-intervention average similarity index of the students was 0.30 ($SD = 0.22$) which increased to 0.39 ($SD = 0.28$) in the post-intervention ratings. This finding shows that the similarity of the students' PFnets with the referent PFnet around control concepts increased or, in other words, the presence of

misconceptions decreased around control concepts when multimedia instruction was used as intervention. The issue of increase in mean similarity index of students' PFnets around control concepts because of multimedia intervention will be further investigated in the section of data analysis for relevant and irrelevant links in the control concepts. The issue will also be discussed later in chapter 4.

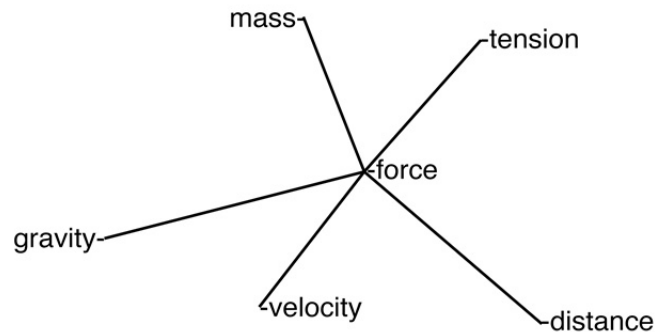
Analysis of Relevant and Irrelevant Links in Treatment Concepts in Students' PFnets

The similarity indices of students' PFnets around treatment concepts can improve either by the increase of relevant links or by the decrease of irrelevant links in the students' PFnets or both. To further explore the results, pre- and post-intervention numbers of the relevant and irrelevant links in treatment concepts (i.e., force, work, and transverse wave) were calculated for each student. These relevant and irrelevant links were compared to the number of links around the treatment concept in the respective referent PFnets as a follow-up test.

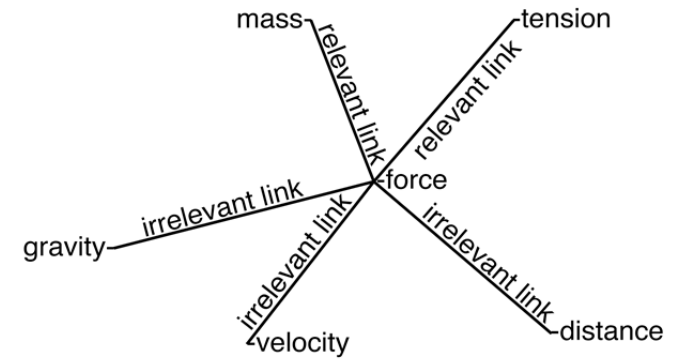
Figures 3.3 through 3.5 illustrate as an example the relevant and irrelevant links of 3 students around the treatment concepts (i.e., the concepts of force, work, and transverse wave). Tables 3.4-3.6 show the number of pre- and post-intervention relevant and irrelevant links in treatment concepts of the students when three types of interventions were implemented.



(a) PFnet of student-22

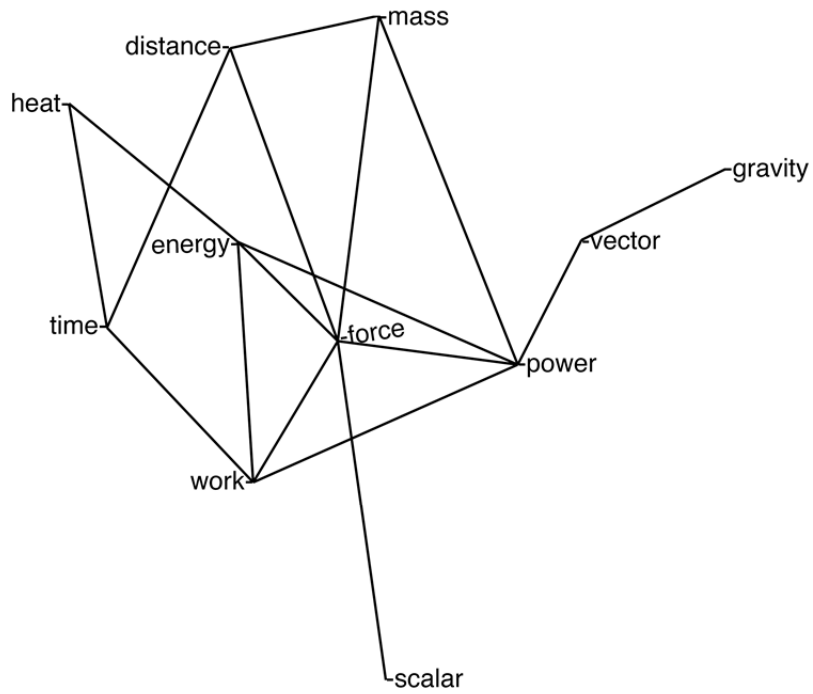


(b) Force concept in PFnet of student-22

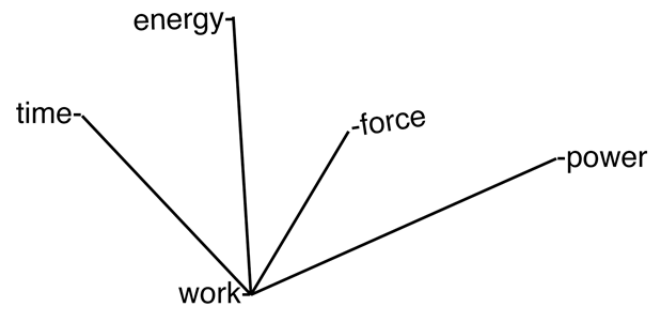


(c) Relevant and irrelevant links in Force concept of student-22

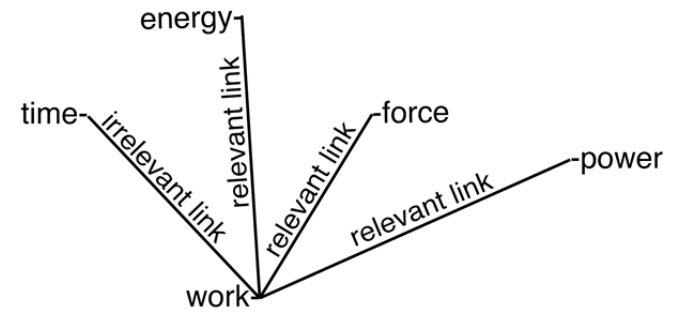
Figure 3.3. Relevant and irrelevant links in student-22 PFnet around the concept of Force.



(a) PFnet of student-122

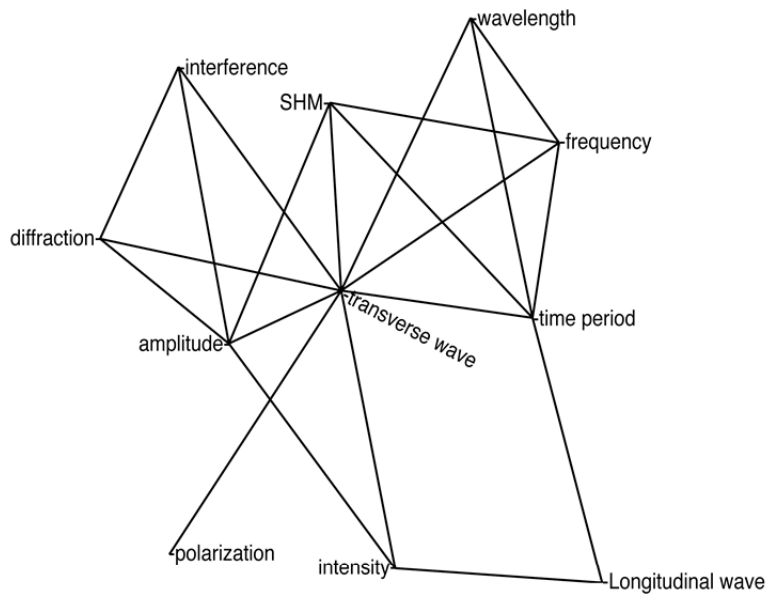


(b) Work concept in PFnet of student-122

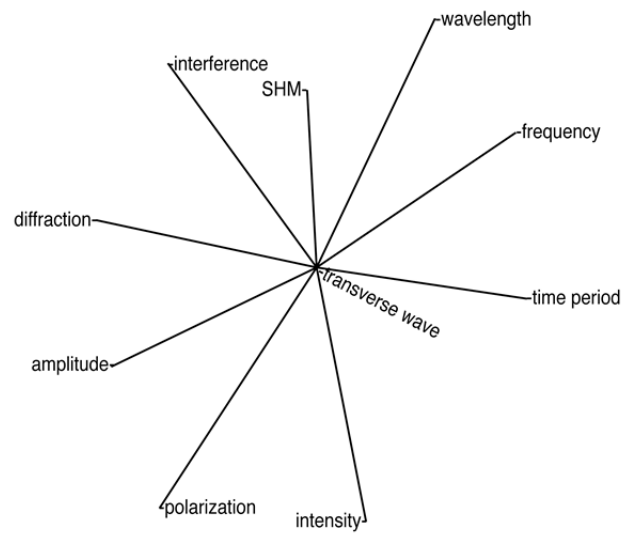


(c) Relevant and irrelevant links in Work concept of student-122

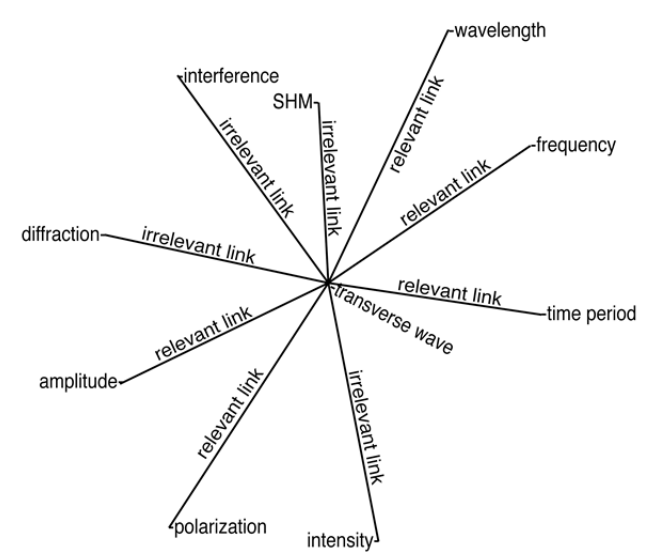
Figure 3.4. Relevant and irrelevant links in student-122 PFnet around the concept of Work.



(a) PFnet of student-188



(b) Transverse wave concept in PFnet of student-188



(c) Relevant and irrelevant links in Transverse wave concept of student-188

Figure 3.5. Relevant and irrelevant links in student-188 PFnet around the concept of Transverse wave.

Table 3.4

Pre- and Post-Intervention Relevant and Irrelevant Links in Treatment Concepts of the Students when Reflections were implemented as Intervention

Links around force concept	Pre-intervention	Post-Intervention	Links around work concept	Pre-intervention	Post-Intervention	Links around transverse wave concept	Pre-intervention	Post-Intervention
Relevant links								
Force-Displacement	17	32	Work-Force	39	49	Transverse wave-Frequency	11	14
Force-Acceleration	20	26	Work-Distance	21	46	Transverse wave-Wavelength	9	19
Force-Tension	28	36	Work-Scalar	23	54	Transverse wave-Time period	13	22
Force-Mass	31	37	Work-Energy	41	51	Transverse wave-Amplitude	11	18
Force-Inertia	26	33	Work-Heat	15	43	Transverse wave-Longitudinal wave	6	24
Force-Momentum	22	26	Work-Power	43	52	Transverse wave-Polarization	9	18
Mean	24	31.67	-	30.33	49.17	-	9.83	19.17
Irrelevant links								
Force-Gravity	19	16	Work-Mass	12	17	Transverse wave-Diffraction	15	4
Force-Velocity	16	12	Work-Time	19	7	Transverse wave-Interference	10	8
Force-Distance	19	15	Work-Gravity	6	10	Transverse wave-Intensity	7	6
Force-Time	10	6	Work-Vector	17	5	Transverse wave-SHM	8	3
Mean	16	12.25	-	13.5	9.75	-	10	5.25

Table 3.5

Pre- and Post-Intervention Relevant and Irrelevant Links in Treatment Concepts of the Students when Written Exercises were implemented as Intervention

Links around force concept	Pre-intervention	Post-Intervention	Links around work concept	Pre-intervention	Post-Intervention	Links around transverse wave concept	Pre-intervention	Post-Intervention
Relevant links								
Force-Displacement	24	23	Work-Force	19	22	Transverse wave-Frequency	24	30
Force-Acceleration	19	25	Work-Distance	19	16	Transverse wave-Wavelength	25	35
Force-Tension	31	34	Work-Scalar	19	17	Transverse wave-Time period	16	35
Force-Mass	35	36	Work-Energy	16	21	Transverse wave-Amplitude	20	31
Force-Inertia	33	25	Work-Heat	7	11	Transverse wave-Longitudinal wave	22	32
Force-Momentum	25	24	Work-Power	16	20	Transverse wave-Polarization	21	36
Mean	27.83	27.83	-	16.0	17.83	-	21.33	33.17
Irrelevant links								
Force-Gravity	21	21	Work-Mass	9	9	Transverse wave-Diffraction	14	17
Force-Velocity	16	8	Work-Time	10	7	Transverse wave-Interference	24	24
Force-Distance	14	14	Work-Gravity	6	5	Transverse wave-Intensity	12	16
Force-Time	6	12	Work-Vector	8	7	Transverse wave-SHM	14	10
Mean	14.25	13.75	-	8.25	7.0	-	16.0	16.75

Table 3.6

Pre- and Post-Intervention Relevant and Irrelevant Links in Treatment Concepts of the Students when Multimedia Instruction was implemented as Intervention

Links around force concept	Pre-intervention	Post-Intervention	Links around work concept	Pre-intervention	Post-Intervention	Links around transverse concept	Pre-intervention	Post-Intervention
Relevant links								
Force-Displacement	14	20	Work-Force	25	36	Transverse wave-Frequency	21	41
Force-Acceleration	15	25	Work-Distance	6	29	Transverse wave-Wavelength	27	46
Force-Tension	26	27	Work-Scalar	15	25	Transverse wave-Time period	22	34
Force-Mass	21	35	Work-Energy	24	29	Transverse wave-Amplitude	13	41
Force-Inertia	20	21	Work-Heat	16	15	Transverse wave-Longitudinal wave	11	43
Force-Momentum	15	24	Work-Power	30	32	Transverse wave-Polarization	22	39
Mean	18.50	25.33	-	19.33	27.67	-	19.33	40.67
Irrelevant links								
Force-Gravity	16	14	Work-Mass	9	11	Transverse wave-Diffraction	14	11
Force-Velocity	10	22	Work-Time	14	5	Transverse wave-Interference	24	10
Force-Distance	12	16	Work-Gravity	4	11	Transverse wave-Intensity	15	9
Force-Time	7	13	Work-Vector	13	7	Transverse wave-SHM	9	1
Mean	11.25	16.25	-	10.0	8.5	-	15.5	7.75

A 3 Type of Instruction (reflection, written exercises, multimedia instruction) \times 2 Type of Links (relevant, irrelevant) \times 2 Time (pre-intervention, post-intervention) within-subjects analysis of variance (ANOVA) on mean number of links was computed. Descriptive statics and associated values were generated. Table 3.7 shows a brief view of these values.

Table 3.7

Mean Number of Relevant and Irrelevant Links in Treatment Concepts as a Function of Type of Instruction (Reflections, Written Exercises, Multimedia Instruction), Type of Links (Relevant, Irrelevant), and Time (Pre-Intervention, Post-Intervention)

	Links			
	Relevant		Irrelevant	
	Pre-intervention Mean (SD)	Post-intervention Mean (SD)	Pre-intervention Mean (SD)	Post-intervention Mean (SD)
Type of Instruction				
Reflection	2.89 (1.35)	4.51 (1.23)	1.19 (.98)	0.82 (.86)
Written exercises	2.94 (1.39)	3.56 (1.45)	1.16 (1.00)	1.13 (1.08)
Multimedia instruction	2.58 (1.21)	4.23 (1.41)	1.11 (.91)	0.98 (1.03)

The three-way interaction was examined first. The interaction among independent variables of type of instruction, type of links, and time was significant with $F(1, 132) = 14.85; p = 0.00$. This three-way interaction can also be seen by comparing graphs in Figures 3.6 and 3.7. Figure 3.6 shows two-way interaction between type of instruction and time for the relevant links whereas Figure 3.7 shows the corresponding two-way interaction for the irrelevant links. Following the three-way interaction, the *type of instruction \times time* two-way interaction was examined separately for the relevant and irrelevant links. Results revealed that the *type of instruction \times time* interaction was significant with $F(1, 132) = 17.47; p = 0.00$ for relevant links and non-significant for irrelevant links at $F(1, 132) = 2.45; p = 0.09$. Thus, three pairwise comparisons for relevant links in the students' PFnets around treatment concepts from pre- to post-intervention phase for each type of instruction were conducted.

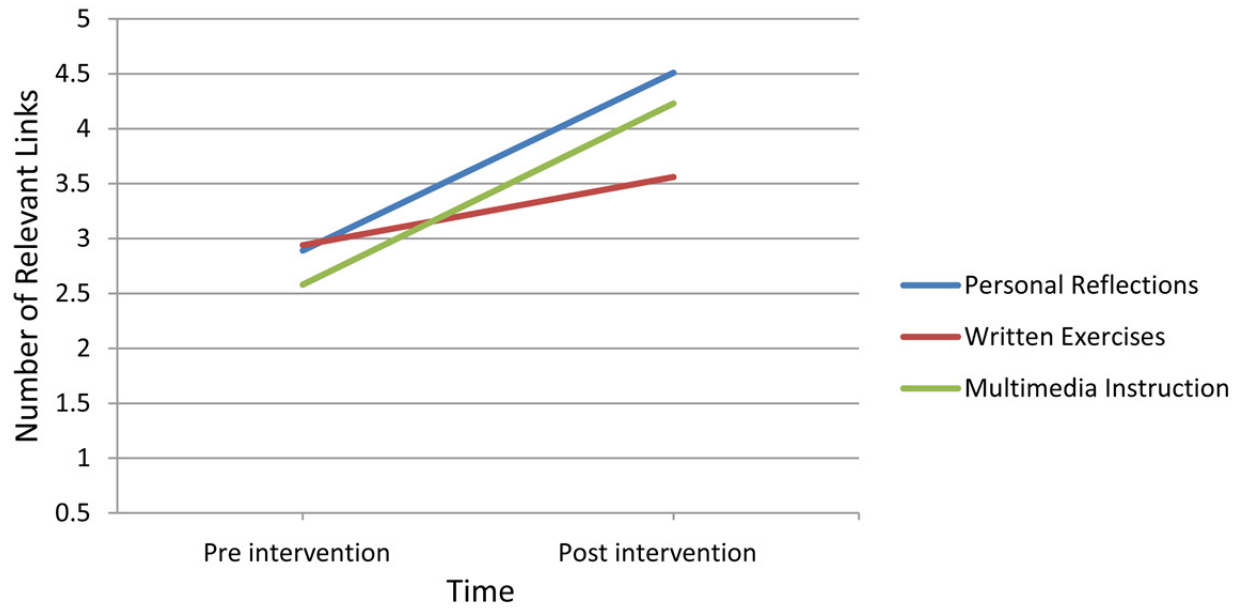


Figure 3.6. Two-way interaction of the relevant links in the treatment concepts when three types of instructions were given.

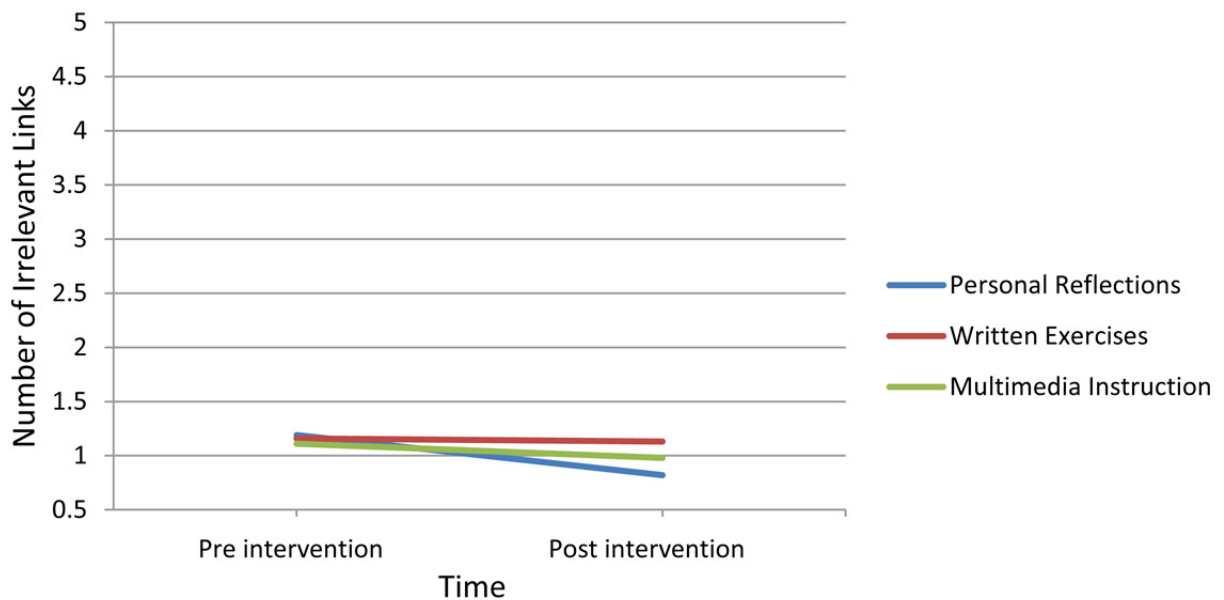


Figure 3.7. Two-way interaction of the irrelevant links in the treatment concepts when three types of instructions were given.

From the first pairwise comparison, the pre-intervention number of mean relevant links in the students' PFnets were 2.89 ($SD = 1.35$) which increased significantly to 4.51 ($SD = 1.23$) in the post-intervention ratings following reflections with $F(1, 132) = 122.85$; $p = 0.00$. This finding shows that the number of relevant links in the students' PFnets increased or, in other words, the presence of missing conceptions decreased substantially when reflections were used as intervention.

From the second pairwise comparison, the pre-intervention mean number of relevant links in the students' PFnets were 2.94 ($SD = 1.39$) which increased to 3.56 ($SD = 1.45$) in the post-intervention ratings following written exercises with $F(1, 132) = 15.26$; $p = 0.00$. This finding shows that the number of relevant links in the students' PFnets increased or, in other words, the presence of missing conceptions decreased substantially when written exercises were used as intervention.

From the third pairwise comparison, the pre-intervention number of mean relevant links in the students' PFnets were 2.58 ($SD = 1.21$) which increased to 4.23 ($SD = 1.41$) in the post-intervention ratings following multimedia instruction with $F(1, 132) = 112.16$; $p = 0.00$. This finding also shows that the number of relevant links in the students' PFnets increased or, in other words, the presence of missing conceptions decreased substantially when multimedia instruction was used as intervention.

As stated earlier, the two-way interaction between *type of instruction* and *time for irrelevant links* was not significant. Therefore, a main effect analysis of variables type of instruction and time for irrelevant links was conducted. This analysis indicated that the main effect of type of instruction was not significant with $F(1, 132) = 1.29$; $p = 0.28$ whereas the main effect of time was significant with $F(1, 132) = 7.27$; $p = 0.01$. The result implies that although

the number of irrelevant links decreased around treatment concepts over the time from pre- to post-intervention, this decrease did not depend on the type of instruction given to the students.

Analysis of Relevant and Irrelevant Links in Control Concepts in Students' PFnets

To address the validity of the research process and further test the hypothesis 2, pre- and post-intervention numbers of relevant and irrelevant links in the PFnet of each student was also investigated around the control concepts (i.e., time, mass, and intensity). Tables 3.8-3.10 show the number of pre- and post-intervention relevant and irrelevant links in control concepts of the students. The mean number of links in control concepts as a function of type of instruction (reflections, written exercises, multimedia instruction), type of links (relevant, irrelevant), and time (pre-intervention, post-intervention) are shown in Table 3.11. Although, the values of all three conditions are provided, only those for the multimedia instruction were further analyzed.

Table 3.8

Pre- and Post-Intervention Relevant and Irrelevant Links in Control Concepts of the Students when Reflections were implemented as Intervention

Links around time concept	Pre-intervention	Post-Intervention	Links around mass concept	Pre-intervention	Post-Intervention	Links around intensity concept	Pre-intervention	Post-Intervention
Relevant links								
Time-Distance	23	24	Mass-Force	51	45	Intensity-Polarization	7	8
Time-Displacement	20	21	Mass-Scalar	37	35	Intensity-Amplitude	10	8
Time-Acceleration	17	20	Mass-Energy	17	18	Intensity-Interference	10	7
Time-Velocity	29	27	-	-	-	-	-	-
Mean	22.25	23.0	-	35.0	32.67	-	9.0	7.67
Irrelevant links								
Time-Force	9	6	Mass-Work	11	17	Intensity-Transverse wave	7	6
Time-Tension	2	3	Mass-Distance	11	13	Intensity-Longitudinal wave	7	9
Time-Mass	5	10	Mass-Heat	6	13	Intensity-Frequency	5	5
Time-Inertia	6	5	Mass-Power	14	9	Intensity-Wavelength	6	14
Time-Momentum	8	10	Mass-Time	7	8	Intensity-Time period	6	4
Time-Gravity	6	5	Mass-Gravity	35	17	Intensity-Diffraction	6	3
-	-	-	Mass-Vector	10	5	Intensity-SHM	10	9
Mean	6.0	6.50	-	13.43	11.71	-	6.71	7.14

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 133.

Table 3.9

Pre- and Post-Intervention Relevant and Irrelevant Links in Control Concepts of the Students when Written Exercises were implemented as Intervention

Links around time concept	Pre-intervention	Post-Intervention	Links around mass concept	Pre-intervention	Post-Intervention	Links around intensity concept	Pre-intervention	Post-Intervention
Relevant links								
Time-Distance	23	26	Mass-Force	26	24	Intensity-Polarization	15	22
Time-Displacement	21	12	Mass-Scalar	12	17	Intensity-Amplitude	18	25
Time-Acceleration	13	19	Mass-Energy	13	12	Intensity-Interference	23	30
Time-Velocity	26	20	-	-	-	-	-	-
Mean	20.75	19.25	-	17.0	17.67	-	18.67	25.67
Irrelevant links								
Time-Force	7	11	Mass-Work	9	9	Intensity-Transverse wave	13	16
Time-Tension	7	6	Mass-Distance	3	5	Intensity-Longitudinal wave	25	27
Time-Mass	11	8	Mass-Heat	4	2	Intensity-Frequency	27	11
Time-Inertia	4	5	Mass-Power	7	5	Intensity-Wavelength	27	14
Time-Momentum	8	9	Mass-Time	9	3	Intensity-Time period	16	14
Time-Gravity	9	7	Mass-Gravity	13	10	Intensity-Diffraction	15	16
-	-	-	Mass-Vector	5	6	Intensity-SHM	21	17
Mean	7.67	7.67	-	7.14	5.71	-	20.57	16.43

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 133.

Table 3.10

Pre- and Post-Intervention Relevant and Irrelevant Links in Control Concepts of the Students when Multimedia Instruction was implemented as Intervention

Links around time concept	Pre-intervention	Post-Intervention	Links around mass concept	Pre-intervention	Post-Intervention	Links around intensity concept	Pre-intervention	Post-Intervention
Relevant links								
Time-Distance	18	19	Mass-Force	31	26	Intensity-Polarization	11	20
Time-Displacement	16	17	Mass-Scalar	15	22	Intensity-Amplitude	20	33
Time-Acceleration	12	17	Mass-Energy	16	15	Intensity-Interference	14	24
Time-Velocity	28	23	-	-	-	-	-	-
Mean	18.50	19.0	-	20.67	21.0	-	15.0	25.67
Irrelevant links								
Time-Force	7	13	Mass-Work	9	11	Intensity-Transverse	14	9
Time-Tension	5	5	Mass-Distance	9	9	Intensity-Longitudinal wave	20	16
Time-Mass	6	12	Mass-Heat	2	5	Intensity-Frequency	20	9
Time-Inertia	5	4	Mass-Power	6	8	Intensity-Wavelength	13	11
Time-Momentum	11	7	Mass-Time	7	4	Intensity-Time period	16	6
Time-Gravity	10	7	Mass-Gravity	11	12	Intensity-Diffraction	10	6
-	-	-	Mass-Vector	6	4	Intensity-SHM	9	8
Mean	7.33	8.0	-	7.14	7.57	-	14.57	9.29

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 133.

Table 3.11

Mean Number of Relevant and Irrelevant Links in Control Concepts as a Function of Type of Instruction (Reflections, Written Exercises, Multimedia Instruction), Type of Links (Relevant, Irrelevant), and Time (Pre-Intervention, Post-Intervention)

	Links			
	Relevant		Irrelevant	
	Pre-intervention Mean (SD)	Post-intervention Mean (SD)	Pre-intervention Mean (SD)	Post-intervention Mean (SD)
Type of Instruction				
Reflection	1.66 (.93)	1.60 (1.03)	1.33 (1.2)	1.29 (1.32)
Written exercises	1.43 (1.02)	1.56 (1.10)	1.80 (1.52)	1.51 (1.37)
Multimedia instruction	1.36 (.89)	1.62 (1.05)	1.47 (1.13)	1.25 (1.18)

The subsequent follow-up test was conducted to find out why there was an increase in similarity of the students' PFnets around the control concepts when multimedia instruction was given. This increase in similarity for the multimedia instruction could have been due to increase in relevant links or decrease in irrelevant links around control concepts. Thus, only a simple two-way interaction for *type of links* \times *time* was conducted for multimedia instruction. This interaction was significant with $F(1, 132) = 6.82; p = 0.01$. Followed by the significant simple two-way interaction for *time* \times *type of links* for multimedia instruction, pairwise comparisons for pre- to post-intervention number of links for control concepts in the multimedia instruction was conducted separately for relevant and irrelevant links. The pairwise comparison for relevant links showed the increase from pre- to post-intervention was significant, with $F(1, 132) = 5.80; p = 0.02$. The pre-intervention mean number of relevant links in students PFnets were 1.36 ($SD = 0.89$) which increased to 1.62 ($SD = 1.05$) in the post-intervention ratings. The mean number of irrelevant links in students PFnets decreased from 1.47 ($SD = 1.13$) in pre-intervention to 1.25 ($SD = 1.18$) in post-intervention ratings, but this decrease in irrelevant links was not significant,

with $F(1, 132) = 2.47; p = 0.12$. This finding suggest that the increase in similarity of the students' PFnets with the referent PFnet around control concepts because of the multimedia instruction was because of increase of relevant links and not because of decrease of irrelevant links in the control concept. The issue of increase of relevant links in the control concepts when multimedia instruction was given will be further discussed in the chapter 4.

Analysis of Personal Reflections of Students

Data analysis showed that students' reflection led to increased similarity around the treatment concepts from pre-to-post intervention as compared to written exercises or multimedia instructions. This follow-up analysis examines more closely the reasons underlying the increase. To investigate further, students' reflections were divided into the following three categories depending on how knowledge was represented in them: 1) conceptual reflection, 2) procedural reflection, and 3) declarative reflection. The coding of reflections by 133 students was done by two coders who were familiar with the physics concepts used in the study. This was done to check the coding reliability for the reflections of students. The two coders independently assigned a code to each of the reflections from the three codes; conceptual reflection, procedural reflection, and declarative reflection. The two sample sheets of coding were then compared to determine agreement or disagreement. Agreement was defined as two coders independently used the same code to a reflection. If there was a mismatch, then it was considered to be disagreement. The result of this check of coding reliability was 76.7% agreement (31 codes out of 133 had disagreement). Next, the two coders considered the 23.3% of reflections and discussed those to reach an agreement code-by-code. Some reflections, or a part of reflections, are cited below to give an idea of the three types of reflections students wrote and their respective codes. In a conceptual reflection, students relate the concept of physics with the real world examples. In a

procedural reflection, students relate the concept with the laws of physics without giving practical examples. In declarative reflection, students may relate a concept with the law of physics but do not reflect on how the concept is related to the law or sometimes they just agree with the statements about the concepts of physics provided to them during the intervention.

Some examples of students' conceptual reflections

- Force and tension are highly related because if we increase the force in the string then the tension also increases. For example, take a loosely stretch string and apply a force, the force will produce tension in the string. Therefore, force and tension are highly related.
- If a person pulls a rope with a greater force then the tension in the rope will be greater. To pull a rope requires force, which means that force is related to tension.
- Force is very much related to acceleration, the more you accelerate an object it will move with more force. For example, if you throw a stone with more force, it will have more acceleration because of the difference between initial and final velocities and finally will hit an obstacle with more force.
- Force and mass are strongly related because if we want to displace a heavy object, more force will be required and if we want to displace a lighter object than less force will be required, i.e., $F \propto m$. It is always easier to move a book rather than a desk.
- Force and acceleration are interrelated because for a car, greater the force applied by the engine, greater will be the acceleration produced by car, so they are directly proportional.

Some examples of students' procedural reflections

- Force and acceleration are strongly related because the two quantities are related by Newton's second law of Motion, $F=ma$.

- Force is strongly related to acceleration and mass, as according to the definition “force is the product of mass and acceleration”. So if the acceleration and mass change then force also changes.
- This was the misconception in my mind that force and acceleration are not related to each other. But Newton’s second law states that when a force acts upon a body, it will accelerate the body in the direction of force. This acceleration is directly proportional to the force applied on the body and inversely proportional to the mass of the body.
- Force is not strongly related to gravity because $W=mg$ and $g=W/m$, so there is no concept of force here in the equation.
- I thought that force and acceleration are not related to each other but according to the Second law of Newton, force is directly proportional to acceleration. It means that they are strongly related to each other.

Some examples of students’ declarative reflections

- Tension is related to force, as tension is also a force.
- Force and acceleration are related to each other because Newton’s second law says that force and acceleration are related.
- Force and acceleration are connected in expert’s network; therefore, they are related to each other.
- I thought that force and acceleration are not related, but I was wrong, because Newton’s second law of motion proves that force is related to acceleration.
- Yes, force is strongly related to acceleration and mass.

Findings about Reflections

The study examined the effectiveness of students’ reflections through the changes in

students' pathfinder networks from pre- to post-intervention phase. The treatment concept and its links with other concepts in a student's network were compared to the same concept in the referent network to calculate similarity indices during pre- and post-intervention stages.

A 3 Type of Reflection (conceptual, procedural, declarative) \times 2 Time (pre-intervention or post-intervention) \times 3 Unit ("motion", "work, energy & power", "wave motion & nature of light") split-plot ANOVA with the repeated measures on the variables time and unit was conducted with similarity between student and referent PFnets around the treatment concepts as the dependent variable. The results of the analysis showed that the change in similarity indices of students was non-significant with $F(4, 124) = 0.25$; $p = 0.91$. Preliminary analyses showed that instructional unit did not interact with either of the other factors and, therefore, was not included in subsequent analyses. Following a nonsignificant interaction, the similarity indices were averaged across the three different units, as categorization of type of reflection did not depend on the unit on which it was written.

To determine whether there is a significant difference among the similarity indices in treatment concepts of the students' PFnets as compared to the referent PFnet before and after their reflections, a 3 Type of Reflection (conceptual, procedural, declarative) \times 2 time (pre-feedback/reflection, post-feedback/reflection) split-plot ANOVA with the repeated measures on the variable time was conducted with similarity between student and referent PFnets around the treatment concepts as the dependent variable. Following a significant interaction between type of reflection and time, $F(2, 130) = 5.41$; $p = 0.01$, the simple effect of type of reflection at pre-feedback/reflection was found to be not significant, $F(2, 130) = 1.53$; $p = 0.22$, but the simple effect of reflection at post-feedback/reflection was significant, $F(2, 130) = 12.12$; $p = 0.00$. These findings show that the participant students had equal number of misconceptions before

intervention, but their misconceptions decreased significantly after writing reflections. Follow-up pair-wise tests to compare post-intervention similarity indices of a reflection with post-intervention similarity indices of other type of reflection were investigated by the independent-samples t -test at a significant value of .05. Follow-up comparisons revealed that students who wrote conceptual reflections had a statistically significantly higher mean post-feedback/reflection similarity index than students who wrote declarative, $t(99) = 4.84$; $p < 0.001$, and procedural, $t(72) = 2.08$; $p = 0.04$, reflections, while the mean similarity index for students who wrote procedural reflections was statistically significantly higher than those who wrote declarative reflections, $t(89) = 2.33$; $p = 0.02$. Table 3.12 shows the mean pre- and post-feedback/reflection similarity indices of the students for each type of reflection around the treatment concepts.

Table 3.12

Mean (and Standard Deviation) Pre- to Post-Intervention Similarity Indices of the Students for each type of Reflection around the Treatment Concepts

Type of reflection	N	Pre-feedback/reflection	Post-feedback/reflection
Conceptual	42	0.41 (0.19)	0.78 (0.16)
Procedural	32	0.45 (0.19)	0.69 (0.18)
Declarative	59	0.38 (0.18)	0.59 (0.20)

The similarity of the students' PFnets with the referent PFnet was increased the most or, in other words, the presence of misconceptions were decreased the most for the students who wrote conceptual reflections, followed by the students who wrote procedural reflections. The misconceptions among the students who wrote declarative reflections were decreased the least. The graph shown in the Figure 3.8 represents the change in similarity indices of students depending on the type of reflection they wrote. The graph shows that students gained more understanding of the subject when they wrote conceptual reflection. Strong evidence was

provided by the study that reflections were effective means of reducing the number of misconceptions the students held.

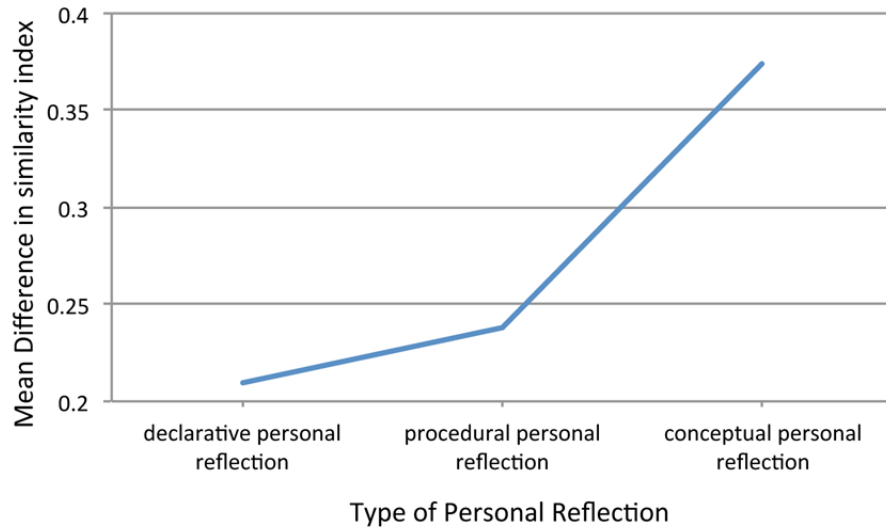


Figure 3.8. A graph between mean difference of similarity index and type of reflection written by the students.

CHAPTER 4: CONCLUSION AND IMPLICATIONS

Teachers prepare, plan and deliver instruction to enhance learning among their students. Bruner (1966) defines instruction as “an effort to assist or shape growth” (p. 1). Instruction should be organized in such a way so that students understand basic scientific concepts without any difficulty. Thus, instructions should be made meaningful for the students in such a way that students are able to attain knowledge and implement their knowledge in a variety of situations. A teacher generally makes decisions about what to teach, which type of teaching aids to use, best instructional strategy to teach selected content and how to implement the lesson in a classroom. These decisions are based on a number of factors, which may include curriculum goals, teacher’s own knowledge about the subject, and teaching strategies. These factors may impact a teacher to decide whether to ask students to give their reflections on the topic of interest and then the teacher analyze those reflections, or a teacher gives written exercises to students to enhance their skills in problem solving, or a teacher implement multimedia instruction in a classroom to engage students around the topic of study.

Understanding misconceptions is the most crucial step for improving classroom instructions (Muller, Sharma, Eklund, & Reimann, 2007). 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).

In this concluding chapter, I will briefly revisit the results of the comparison of three types of remedial instructions and conclusion I have drawn from the study. For this comparison, assessment of students' pathfinder similarity indices around treatment and control concepts was undertaken, whereas instructions were given to the students only around the treatment concepts. After discussing some limitations of the study, I will conclude the chapter with the implications for future research.

Summary of the Findings

From this study, we can make several conclusions about conceptual understanding and misconceptions in physics using structural assessment of knowledge, with a focus on three types of remedial instruction that was given to the participant students.

Firstly, students acquired some degree of conceptual knowledge about treatment concepts in the study following the intervention. As an intervention, three types of instructions were given to the students. These instructions were targeted towards misconceptions identified in their PFnets. Considering pre-interventions similarity of students' PFnets around the treatment concepts with the referent network as the baseline, the change in the post-intervention similarity served as a baseline for assessing possible conceptual change among the students. Clearly, it is important to inform the students that they have certain misconceptions within the context of science by showing them their own and referent network. Although, sharing referent network with the students fosters better knowledge structure of students (Trumpower & Goldsmith, 2004), the students might benefit from even more feedback and exercises on how these concepts are interrelated, and when that feedback was given, the researcher observed changes in their network representations. This improvement was evident in the subsections of the students'

PFnets about which different types of instructions were given. Each of the three types of remedial instructions showed that they brought improvement in the treatment concepts (the concepts of force, work, and transverse wave) from pre- to post-intervention. Based on the mean change in the similarity indices, the pairwise comparison performed from pre-intervention and post-intervention similarity indices of students' PFnets around treatment concepts showed that reflections improved the misconceptions of the students the most. The study divided reflections into three categories—conceptual reflections, procedural reflections and declarative reflections. The findings further argue that whereas all three types of reflections improved knowledge of students by addressing their misconceptions, the similarity of the students' PFnets with the referent PFnet was increased the most when students wrote conceptual reflection, followed by procedural reflection and declarative reflection respectively. It seems that bridging between prior knowledge and the knowledge currently attained by the student helps students to gain conceptual knowledge and to overcome their misconceptions. That is, for example, just knowing that force and acceleration are related, or that $F = ma$ (and remembering this fact) is not the most effective way to gain conceptual understanding. Connecting these facts (i.e., application of them) with the real world is more beneficial.

The pairwise comparison performed from pre-intervention and post-intervention similarity indices of students' PFnets around treatment concepts showed that multimedia instruction and written exercises also improved the misconceptions of the students. Although the researcher did not formally compare three types of interventions, it was found that all three types of instructions given to the students relinquished their misconceptions. The three-way interaction performed during data analysis for the treatment concept was significant, indicating that the extent to which three types of instructions performed differently. The visual inspection of the

pre-post increases of similarity indices (see Figure 3.1) suggested that reflections worked best, followed by multimedia instructions, and then written exercises.

The improvement in the subsections of the students' PFnets around control concepts was not significant for reflections and written exercises, but it was significant when multimedia instruction was given to the students. The reason for having the significant change in control concepts when multimedia instructions were given could be because of the lack of focus of multimedia instruction on particular treatment concepts. Video clips shown to the students during the intervention always linked the main concept with other concepts to construct knowledge about the main concept itself. For example, a video clip showing the relation between force and acceleration has to also somehow show the relation between force and velocity, because acceleration is the change in velocity. When students view such a clip, besides constructing knowledge about the relationship of force and acceleration (i.e., a treatment concept in the unit "motion"), they also construct knowledge about the relationship of force and velocity (i.e., a control concept in the unit "motion"). Therefore, students might also obtain information about the control concepts during the multimedia session. It might be noted that although there was an improvement (from a mean value of 0.30 to 0.39) in the control concepts, due to multimedia instruction, the improvement was very small.

It is very difficult to make or collect video clips for multimedia instruction that are explicitly around one specific concept or relationship. Consequently, students saw more than one relationship during the multimedia instruction, which thereby also improved some of their control concepts too. The question arises here: Is it possible to come up with a multimedia instruction focused on just one particular concept or relationship? To answer that, it must be stated that it is not so much the multimedia instruction itself that transfers across the treatment

concept to the control concept, rather the way those particular multimedia instructions are structured. If the written exercises would have a similar pattern of providing some information about control concepts, then they might generate the same effect. To summarize the argument, the researcher did not create the video clips for the multimedia instructions; instead the researcher just collected them. However, the written exercises were created specifically around the treatment concepts, where the reflection represents the personal opinion of the students about the treatment concepts. Therefore, the increase in similarity index around control concepts is not because multimedia instruction had some power to transfer to control concepts, but just the fact that the particular multimedia instructions that were used for the study covered a broader range of concepts as compared to the written exercises or reflections.

Secondly, consistent with the preceding findings, evidence (in the form of significant treatments and interaction effects) was provided by the study that effects of reflections, written exercises and multimedia instruction on relevant links in treatment concepts were effective means of reducing the number of misconceptions the students held, and significantly improved the students' similarity of treatment concepts with the respective referent PFnets. The finding for the relevant links was consistent with the findings when the treatment concepts was considered and compared it with the respective subsection of referent PFnets. The number of relevant links in the students' PFnets with the referent PFnets were increased the most or, in other words, the presence of missing conceptions were decreased the most when students were asked to write reflections as an intervention, followed by when students were given multimedia instruction as an intervention or written exercises respectively. Mean number of relevant links in the treatment concepts from pre-intervention to post-intervention went up from 2.89 to 4.51 when reflections were implemented as an intervention, and it was significant. It is also true for the written

exercises where mean number of relevant links from pre-intervention to post-intervention went up from 2.94 to 3.56 and for multimedia instruction it went up from 2.58 to 4.23 and both were significant too. The results of the study also showed (in the form of significant main effect of variable time) that number of irrelevant links in the students' PFnets with the referent PFnets were decreased over the time from pre- to post-intervention because of instruction. It was further shown that the main effect of variable instruction was not significant. Essentially it shows that there is a change across time but it did not differ for three different types of instructions for irrelevant links in the treatment concepts. So if there is a decrease in irrelevant links in the treatment concepts because of three types of instructions, there is an equal decrease for all three types of instructions. If we look at the overall means for irrelevant links from pre-intervention to post-intervention to describe the situation, it looks like:

1. Mean number of irrelevant links for reflections from pre-intervention to post-intervention decreased from 1.19 to 0.82
2. Mean number of irrelevant links for written exercises from pre-intervention to post-intervention decreased from 1.16 to 1.13
3. Mean number of irrelevant links for multimedia instruction from pre-intervention to post-intervention decreased from 1.11 to 0.98

Average number of irrelevant links went down approximately equally but the fact that there was a time effect suggests that there was a significant decrease in number of irrelevant links but it was of equal or identical magnitude for reflections, written exercises, or multimedia instruction. That was the reason why there was no two-way interaction between *type of instruction* \times *time* for irrelevant links because the number of irrelevant links in the treatment concepts went down similarly. Therefore, the analysis for the counting of relevant and irrelevant

links around the treatment concepts verify the initial findings that say that the reflections reduced misconceptions of the students the most followed by multimedia instruction whereas written exercises also reduced misconceptions among the students significantly but the contribution was not as big as by the other two.

To summarize, it was shown that there was an increase in the similarity index of the students' PFnets as compared to the referent PFnets around the treatment concepts. This all depends on the type of instructions given to the students, with the reflections and multimedia instruction doing better than the written exercises. Now the results are broken down to see why there is an improvement and that shows us that the improvement is dependent on the relevant and irrelevant links around treatment concepts. The increase in the relevant links in the students' PFnets is very consistent with the results of similarity index of the students' PFnets as compared to the referent PFnet around the treatment concepts. The results show that number of relevant links around treatment concept increases across the board but more so in the reflections and multimedia instruction than written exercises. However, it is found that there is a decrease in irrelevant links around the treatment concepts, which does not depend on the type of instructions. These irrelevant links decrease in all the three cases approximately equally. Putting the results together, the reason that pathfinder similarity is more impressive for the reflections and multimedia instruction is because of an increase in relevant links rather than a decrease in the irrelevant links around the treatment concepts.

These results may raise a question that why reflections and multimedia instruction led to greater acquisition of relevant links than the written exercises, but the three interventions were equal in reducing the number of irrelevant links. One possible answer could be that when reflections were implemented as an intervention, students not only wrote about their missing

links as compared to the referent PFnets and but also about extra links they have in their PFnets as compared to the referent PFnet. This exercise helped them to reduce a greater number of irrelevant links as compared to other type of interventions apart from increasing number of relevant links in their PFnets. Multimedia instruction also generated knowledge around related links but also impart some knowledge about irrelevant links too. But the written exercises were mostly streamlined around related concepts and did not generate any knowledge around irrelevant links. The written exercises were more procedural and procedural intervention is not good at showing irrelevant links.

Thirdly, as the instructions were not given to the students around control concepts (time, mass, and intensity), therefore, the similarity indices of control concepts in the pathfinder networks of the students did not improve significantly from pre- to post-intervention. It was shown before that there was a slight improvement in mean similarity index of students around control concept when multimedia instruction was given as an intervention, the study further explored to see if the improvement is because of increase in relevant links or decrease in irrelevant links around the control concepts. Pairwise comparisons of multimedia instruction from pre-intervention to post-intervention separately for relevant and irrelevant links in the control concept were conducted. Because there was no change in the mean similarity index for reflection and written exercises conditions across time, therefore, follow-up of those two were not conducted. The pairwise comparison found that when multimedia instruction was given, the improvement in the similarity of students' PFnets was because of significant increase of relevant links from an average value of 1.36 to 1.62 but there was no significant change in irrelevant links. The three control concepts (time, mass, and intensity) were not directly focused in the three types of instructions. This small improvement in the control concepts because of multimedia instruction is discussed above.

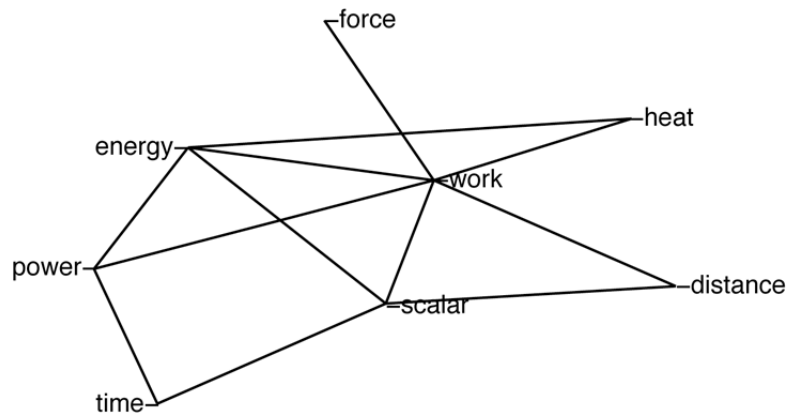
Limitations of the Study

Inevitably, this study is bounded by the quality and the context of the research. 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, is limited by its own contextual nature and limitations. The concepts chosen to represent units on “motion”, “work, energy & power” or “wave motion & nature of light” were based on the opinion of Grade 11 physics instructors. Different instructors or experts outside the academic setting of the school may choose different concepts, which could produce different findings. Instructors generally teach a variety of students whose intellectual capacities, and interests are diverse. To manage such a situation, they give up personal views of physics, at least partially, and try to make some meaning that physics may have for their students. This condition might have an adverse effect on the ratings of the instructors taken to make a referent network; the instructors might be less conceptual and more procedural in the classroom but when filling the rating task they might have shown their full conceptual understanding of physics concepts.

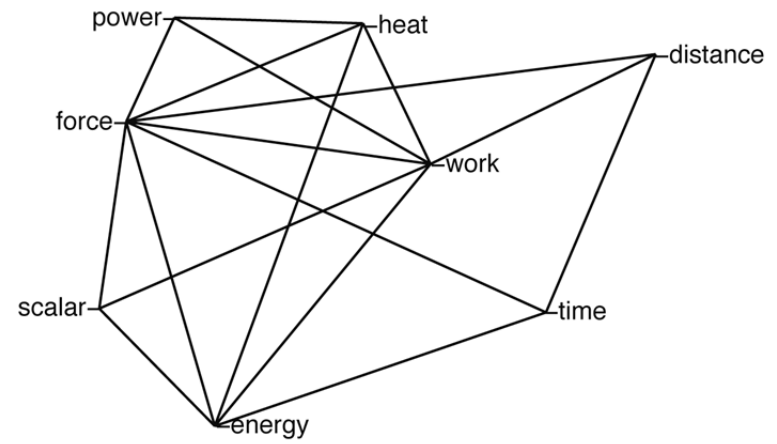
Another limitation of the present study is that the type of reflection that students performed with the structural feedback was not experimentally manipulated. Therefore, it is not clear if the relationship between type of reflection and post-feedback/reflection structural knowledge was causal or not. In either case, the results have implications for educators. If the relationship is causal, then prompting students to reflect conceptually on structural feedback – i.e., encouraging them to think of concrete examples from the real world that illustrate the concept relations they are trying to learn – is indicated. Alternatively, if the amount to which students benefitted from structural feedback and the tendency to reflect conceptually simply co-occurred in a non-causal manner, then an implication is that identification of a student’s preferred mode of reflection might

be used to determine the most effective type of feedback for them to receive. Students who think conceptually can be expected to benefit most from structural feedback, whereas other students who think more procedurally or declaratively might be found to benefit more from other types of feedback. Further, the instruction given to the students for reflection included the excerpt “many expert scientists think that . . .” Therefore, it is also not clear if students changed their ratings of concept relatedness after reflection simply because an expert told them that they should, or if they changed their ratings as a result of a real increase in understanding of the concept relationships. It may be noted, though, that about half of the students were able to reflect conceptually or at least procedurally for the conceptual relationships that they did not initially understand, thus indicating a real improvement in understanding. However, the other half could only provide declarative explanations. So, it looks like at least half of the students’ improvements reflected real increases in understanding, whereas the other half may have may have been superficial.

Factors which influence the lack of an effect of different types of instructions may include: lack of familiarity with multimedia use, prior knowledge related to a particular concept, student preoccupation with exams and studies. Although the experimental instruction are idealized in many ways, when compared to a real verbal instruction it has some disadvantages too. In a verbal instruction, students can stop their instructor and ask questions. The instructor as well, may notice if the student do not understand the topic and respond to it effectively. An instructor can also request students’ participation at any time during the process of instruction. So, it is possible that these advantages of a verbal instruction may counterbalance some of the positive aspects of different types of instructions proposed in this study. Practical disadvantages of implementing multimedia instruction must also be considered. With verbal feedback, an instructor always have enough time to cover all the important issues, multimedia instruction can be a burden because of the extra material and hence time it requires.



(a) Student-14's work concept



(b) Student-180's work concept

Figure 4.1. Two different work concepts with same similarity index.

There are many 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 treatment and control concepts lies in the technique to calculate this index. For example, the work concepts of the pathfinder networks of the student-14 and student-180 are shown in Figure 4.1(a, b). The similarity index for both the students around the treatment concepts (i.e., the concept of work) was calculated as 1, because both the students' work concept contains all the related links as the referent PFnet has. Under this condition both the student-14 and student-180 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. 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 pairwise comparisons increases exponentially with each concept added to the list. For example, a list of 11 concepts, as used in this study, results in 55 pairwise comparisons, but a list of 20 concepts results in 190 pairwise 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 4.2. Therefore, it seems reasonable to include only the important concepts in the list.

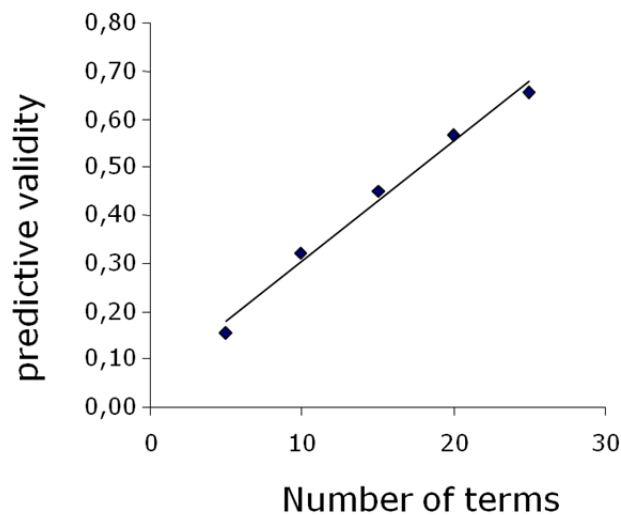


Figure 4.2. Graph between mean predictive validity and number of terms used in a sample.

Implication for Future Research

Exploration and the understanding of students’ misconceptions and the effect of different types of remedial instructions on misconceptions have several implications for future research.

The pathfinder network technique is very efficient and effective for the display of complex

relationships among concepts in a particular domain (Zhang, 2008). Therefore, by conceptualizing the knowledge structures of students through concept maps, developed by using pathfinder networks, the study compared effectiveness of three types of remedial instructions (reflections, written exercises, and multimedia instruction). Examining other types of instructions can enrich the future research in this field. 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 instructors.

An important implication of the study is to give individualized remedial instruction based on a learner's misconceptions to one group of students whereas other group can be given instruction around the treatment concept as done in this study. A researcher then can compare the post-intervention pathfinder networks of two groups of students to determine whether individualized feedback (i.e., instruction given to a student around his/her own misconceptions shown by pathfinder network) or collective feedback (i.e., instruction given to students around all the misconceptions the group has) worked better.

Pathfinder network has strength in the evaluation of a kind of knowledge that is essential for cognitive skill development in a classroom. A number of cognitive scientists have compared PFnets with other scaling techniques and found that PFnets provide a useful tool for revealing conceptual structure and for correctly classifying experts and novices (Cooke, Durso, & Schvaneveldt, 1986; Goldsmith & Johnson, 1990; Schvaneveldt, 1990; Trumppower & 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. Through the improvement of understanding among the students, the study compared three types of instructions. For the sake of this comparison, the study indicated

specifically *which subsection* the students' pathfinder networks differ. Therefore, the research demonstrates the potential utility of studying subsets of a pathfinder network. The subset of networks thus generated provided insights needed to identify partially-understood and misunderstood concepts by the students at a single concept level to compare three types of instructions more effectively. 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 instruction, 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.

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. Therefore, instructors may consider this methodology as an additional technique to assess the performance of their students for change in instructional strategy. 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.

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.

The study also extends the literature on reflection as a pedagogical activity, demonstrating the effectiveness of reflection on one's structural knowledge. Furthermore, when students were prompted to reflect, some students wrote more insightful, conceptual reflections than others, whereas some students did it more procedurally and others more declaratively. Conceptual reflection proved to be more effective than other forms of reflection. Reflection in which students were able to link their prior knowledge of concrete examples with new knowledge of conceptual relationships as identified in the referent structure was associated with greater improvements in structural knowledge. This has an important implication for educators that simply giving feedback is not enough—students must engage with the feedback, making it personal, in order to be most effective (Good, 2011; Sadler, 2010). It is not known if students who wrote procedural or

declarative reflections would be able to reflect based on conceptual knowledge if prompted to do so, or if they would benefit to the same extent as the students who did so. Therefore, another extension of the study could be to prompt students to reflect conceptually, rather than declaratively or procedurally, on structural feedback—i.e., encouraging them to think of concrete examples from the real world that illustrate the concept relationships they are trying to learn. Although more studies are required to make these determinations, I believe that all students can benefit from becoming actively engaged in considering their knowledge structures.

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Appendix A: Letter of Information

Comparing the effect of three types of remedial instructions based on structural assessment feedback on learners' misconceptions

The purpose of this research study, which is a part of the requirements for my Ph.D. (Education), is to assess students' misconceptions in the domain of physics and to compare three types of remedial instructions (reflections, written exercises, and multimedia instruction). Many students express difficulties in learning physics concepts because of the 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 stages of the study and each stage comprises of two sessions. Both sessions of one stage will take approximately 30 minutes each to be completed. This means that you will attend six sessions of approximately 30 minutes each.

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 identify students' understanding and misconceptions.

2. As a part of the intervention, after giving students an individualized feedback based on their understanding and misconceptions identified in step 1, different types of remedial instructions will be given to the students at three separate stages. During the first stage, students will be shown their and their instructor's pathfinder networks, and will be asked to reflect on the similarities and differences between them. Written exercises based on these differences will be given at the second stage, and multimedia instruction will be given to the students at the third stage.
3. After each stage, students' pathfinder networks will be reassessed and the similarities between students' and their instructor's pathfinder networks will be calculated. The study will determine if any of the instruction improves the knowledge structure of the students and, if so, which has the greatest effect.

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 the researcher and the thesis supervisor Dr. David Trumpower. 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 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 or my thesis supervisor, Dr. David Trumpower. 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. 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

Dr. David Trumpower
Thesis Supervisor
University of Ottawa

Appendix B: Recruitment Text for the Teacher

My name is Gul Shahzad Sarwar and I am a Ph.D. (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 assess students' misconceptions in the domain of physics and to compare three types of remedial instructions (reflections, written exercises, and multimedia instruction). The study will assess the knowledge structure of students and their instructors using pathfinder networks. Instructors' pathfinder networks will be averaged to create a referent pathfinder network. Each student's pathfinder network will be compared with the referent pathfinder network in order to identify misconceptions. These misconceptions will serve as the basis for remedial instruction.

I am looking for a volunteer physics instructor teaching at grade 11 to participate in this research project. In this experiment you will use a rating scale for pairwise comparison of concepts in the domain of physics.

If you are willing to participate, there will be three stages of the study and each stage comprises of two sessions. Both sessions of a stage will take approximately 30 minutes each to be completed. This means that you will attend six sessions of approximately 30 minutes each. Therefore, the total time required from you as a participant is approximately 3 hours.

Three different types of remedial instructions will be given to the students at three separate stages during these sessions. During the first stage, students will be shown their own and referent pathfinder networks, and will be asked to reflect on the similarities and differences between them. The researcher will give written exercises based on the differences at the second

stage, and multimedia instruction based on the differences will be given to the students at the third stage. 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 six sessions by completing the pairwise 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. 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

Dr. David Trumpower
Thesis Supervisor
University of Ottawa

Appendix C: Consent Form for the Teacher**Comparing the effect of three types of remedial instructions based on structural assessment feedback on learners' misconceptions**Researcher

Gul Shahzad Sarwar
Faculty of Education
University of Ottawa

Research Supervisor

Dr. David Trumpower
Thesis Supervisor
University of Ottawa

You are invited to participate in the above mentioned research conducted by Gul Shahzad Sarwar. The purpose of this research is to explore the appropriateness of three types of remedial instructions (reflections, written exercises, and multimedia instruction) for the learning process after giving feedback to students about their 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 which type of instruction (reflections, written exercises, or multimedia instruction) best address the misconceptions of students and hence improves their knowledge structure. 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 of Canada, 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 you 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.

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 D: Recruitment Text for the Students

My name is Gul Shahzad Sarwar and I am a Ph.D. (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 120 students taking a credit course in physics at grade 11 to participate in an experiment in which you will use a rating scale for pairwise comparison of concepts in the domain of physics. The purpose of the experiment is to assess students' misconceptions in the domain of physics and to compare three types of remedial instructions (reflections, written exercises, and multimedia instruction). The study will assess the knowledge structure of students and their instructors using pathfinder networks. Instructors' pathfinder networks will be averaged to create a referent pathfinder network. Each student's pathfinder network will be compared with the referent pathfinder network in order to identify misconceptions. These misconceptions will serve as the basis for remedial instruction.

If you are willing to participate, there will be three stages of the study and each stage comprises of two sessions. Both sessions of a stage will take approximately 30 minutes each to be completed. This means that you will attend six sessions of approximately 30 minutes each. Therefore, the total time required from you as a participant is approximately 3 hours. Three different types of remedial instructions will be given to you at three separate stages during these sessions. During the first stage, students will be shown their own and referent pathfinder networks, and will be asked to reflect on the similarities and differences between them. The researcher will give written exercises based on the differences at the second stage, and

multimedia instruction based on the differences will be given to the students at the third stage. 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. 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

Dr. David Trumpower
Thesis Supervisor
University of Ottawa

Appendix E: Consent Form for the Parents

Comparing the effect of three types of remedial instructions based on structural assessment feedback on learners' misconceptions

Researcher

Gul Shahzad Sarwar
Faculty of Education
University of Ottawa

Research Supervisor

Dr. David Trumpower
Thesis Supervisor
University of Ottawa

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 find out about the appropriateness of three types of remedial instructions (reflections, written exercises, and multimedia instruction) for the learning process. There are three stages of the study and each stage comprises of two sessions. Both sessions of one stage will take approximately 30 minutes each to be completed.

If you allow your child to participate in this study, your child will attend six sessions of approximately 30 minutes each. The study will be conducted 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 instruction to address his or her misconceptions. The instruction will be based on his or her reflection, written exercises, and also multimedia instruction, such as video-clips, synthetic videos, or multimedia slides. The study will explore which specific type of instruction best improves the conceptual understanding of the participants. 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 of Canada, 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 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 or my thesis supervisor, Dr. David Trumpower. 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. You are given two copies of the consent form. To indicate your decision for your child's participation in this study, please sign both copies of the consent form and send only one copy back with your child. The second copy of the consent form is for your record.

I have read and understood the request for my child to participate in the study of "comparing the effect of three types of remedial instructions based on structural assessment

feedback on learners' misconceptions". 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 F: Assent Form**Comparing the effect of three types of remedial instructions based on structural assessment feedback on learners' misconceptions**

Researcher
Gul Shahzad Sarwar
Faculty of Education
University of Ottawa

Research Supervisor
Dr. David Trumpower
Thesis Supervisor
University of Ottawa

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. A complete introduction to the study is given in the information letter given to you with the assent form.

I am interested in identifying partially understood and misunderstood concepts by students in the domain of physics. This will help me to prepare lessons intended to clarify misconceptions. After completing three different types of lessons (reflections, written exercises, and multimedia instruction) at three separate stages, I will assess the students' knowledge for a change in their understanding after each stage. This will enable me to report changes in the conceptual understanding of physics in the participants due to different types of instructions.

The information collected for this study is confidential and protected under the Municipal Freedom of Information and Protection of Privacy Act of Canada, 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. You are given two copies of the assent form. Sign both copies of the assent form to indicate your decision to participate in this study and return only one copy to the researcher. The second copy of the assent form is for your record. Your parent(s) have also been asked to permit your participation in this study.

Student's name: _____

Signature: _____ Date: _____

Appendix G: Questionnaire 1

Name (please PRINT): _____ Gender: _____

Last year's physics marks (theory + practical): _____

This is a relational test, which will be used to give you feedback about your misconceptions. 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
Crow
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	①	2	3	4	5	Circle “1” if you feel they are less related
Bat	Crow	1	2	③	4	5	
Chicken	Mammal	①	2	3	4	5	Circle “5” if you feel they are more related
Bat	Chicken	1	②	3	4	5	
Bird	Crow	1	2	3	4	⑤	

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 from “Motion”

Directions: List of eleven concepts to be rated:

1. Distance
2. Displacement
3. Force
4. Gravity
5. Velocity
6. Mass
7. Acceleration
8. Momentum
9. Time
10. Inertia
11. Tension

These terms are broadly related to “Motion”. 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
Displacement	Force	1	2	3	4	5
Time	Inertia	1	2	3	4	5
Tension	Acceleration	1	2	3	4	5
Gravity	Distance	1	2	3	4	5
Time	Tension	1	2	3	4	5
Tension	Force	1	2	3	4	5
Gravity	Time	1	2	3	4	5
Distance	Tension	1	2	3	4	5
Force	Mass	1	2	3	4	5
Momentum	Tension	1	2	3	4	5
Gravity	Velocity	1	2	3	4	5
Displacement	Momentum	1	2	3	4	5
Velocity	Force	1	2	3	4	5
Acceleration	Displacement	1	2	3	4	5
Momentum	Acceleration	1	2	3	4	5
Force	Time	1	2	3	4	5
Mass	Displacement	1	2	3	4	5
Distance	Acceleration	1	2	3	4	5
Time	Displacement	1	2	3	4	5
Acceleration	Time	1	2	3	4	5
Displacement	Gravity	1	2	3	4	5
Momentum	Force	1	2	3	4	5
Acceleration	Velocity	1	2	3	4	5
Gravity	Acceleration	1	2	3	4	5
Acceleration	Force	1	2	3	4	5
Inertia	Acceleration	1	2	3	4	5
Tension	Displacement	1	2	3	4	5
Mass	Velocity	1	2	3	4	5
Velocity	Inertia	1	2	3	4	5
Time	Momentum	1	2	3	4	5
		Less Related				More Related

		Less Related				More Related
Force	Gravity	1	2	3	4	5
Velocity	Momentum	1	2	3	4	5
Mass	Time	1	2	3	4	5
Displacement	Distance	1	2	3	4	5
Momentum	Mass	1	2	3	4	5
Inertia	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	Momentum	1	2	3	4	5
Tension	Velocity	1	2	3	4	5
Force	Inertia	1	2	3	4	5
Tension	Mass	1	2	3	4	5
Gravity	Tension	1	2	3	4	5
Inertia	Tension	1	2	3	4	5
Distance	Momentum	1	2	3	4	5
Inertia	Distance	1	2	3	4	5
Displacement	Inertia	1	2	3	4	5
Time	Velocity	1	2	3	4	5
Momentum	Inertia	1	2	3	4	5
Velocity	Displacement	1	2	3	4	5
Acceleration	Mass	1	2	3	4	5
Velocity	Distance	1	2	3	4	5
Inertia	Mass	1	2	3	4	5
Force	Distance	1	2	3	4	5
Tension	Momentum	1	2	3	4	5
Time	Acceleration	1	2	3	4	5
Velocity	Tension	1	2	3	4	5
Mass	Time	1	2	3	4	5
Force	Mass	1	2	3	4	5
		Less Related				More Related

Appendix H: Questionnaire 2

Name (please PRINT): _____ Gender: _____

Last year's physics marks (theory + practical): _____

This is a relational test, which will be used to give you feedback about your misconceptions. 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
Crow
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	①	2	3	4	5	Circle “1” if you feel they are less related
Bat	Crow	1	2	③	4	5	
Chicken	Mammal	①	2	3	4	5	Circle “5” if you feel they are more related
Bat	Chicken	1	②	3	4	5	
Bird	Crow	1	2	3	4	⑤	

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 from “Work, Power and Energy”

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, Power and Energy”. 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
Time	Scalar	1	2	3	4	5
		Less Related				More Related

		Less Related				More Related
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
Mass	Time	1	2	3	4	5
Force	Mass	1	2	3	4	5
		Less Related				More Related

Appendix I: Questionnaire 3

Name (please PRINT): _____ Gender: _____

Last year's physics marks (theory + practical): _____

This is a relational test, which will be used to give you feedback about your misconceptions. 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
Crow
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	①	2	3	4	5	Circle “1” if you feel they are less related
Bat	Crow	1	2	③	4	5	
Chicken	Mammal	①	2	3	4	5	Circle “5” if you feel they are more related
Bat	Chicken	1	②	3	4	5	
Bird	Crow	1	2	3	4	⑤	

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 from “Wave Motion and Nature of Light”

Directions: List of eleven concepts to be rated:

1. Wavelength
2. Frequency
3. Time period
4. Amplitude
5. Intensity
6. Interference
7. Diffraction
8. Polarization
9. Transverse wave
10. Longitudinal wave
11. SHM

These terms are broadly related to “Wave Motion and Nature of Light”. 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
Frequency	Time period	1	2	3	4	5
Transverse wave	Longitudinal wave	1	2	3	4	5
SHM	Diffraction	1	2	3	4	5
Amplitude	Wavelength	1	2	3	4	5
Transverse wave	SHM	1	2	3	4	5
SHM	Time period	1	2	3	4	5
Amplitude	Transverse wave	1	2	3	4	5
Wavelength	SHM	1	2	3	4	5
Time period	Interference	1	2	3	4	5
Polarization	SHM	1	2	3	4	5
Amplitude	Intensity	1	2	3	4	5
Frequency	Polarization	1	2	3	4	5
Intensity	Time period	1	2	3	4	5
Diffraction	Frequency	1	2	3	4	5
Polarization	Diffraction	1	2	3	4	5
Time period	Transverse wave	1	2	3	4	5
Interference	Frequency	1	2	3	4	5
Wavelength	Diffraction	1	2	3	4	5
Transverse wave	Frequency	1	2	3	4	5
Diffraction	Transverse wave	1	2	3	4	5
Frequency	Amplitude	1	2	3	4	5
Polarization	Time period	1	2	3	4	5
Diffraction	Intensity	1	2	3	4	5
Amplitude	Diffraction	1	2	3	4	5
Diffraction	Time period	1	2	3	4	5
Longitudinal wave	Diffraction	1	2	3	4	5
SHM	Frequency	1	2	3	4	5
Interference	Intensity	1	2	3	4	5
Intensity	Longitudinal wave	1	2	3	4	5
Transverse wave	Polarization	1	2	3	4	5
		Less Related				More Related

		Less Related				More Related
Time period	Amplitude	1	2	3	4	5
Intensity	Polarization	1	2	3	4	5
Interference	Transverse wave	1	2	3	4	5
Frequency	Wavelength	1	2	3	4	5
Polarization	Interference	1	2	3	4	5
Longitudinal wave	Amplitude	1	2	3	4	5
Wavelength	Transverse wave	1	2	3	4	5
Interference	Amplitude	1	2	3	4	5
Wavelength	Interference	1	2	3	4	5
Amplitude	Polarization	1	2	3	4	5
SHM	Intensity	1	2	3	4	5
Time period	Longitudinal wave	1	2	3	4	5
SHM	Interference	1	2	3	4	5
Amplitude	SHM	1	2	3	4	5
Longitudinal wave	SHM	1	2	3	4	5
Wavelength	Polarization	1	2	3	4	5
Longitudinal wave	Wavelength	1	2	3	4	5
Frequency	Longitudinal wave	1	2	3	4	5
Transverse wave	Intensity	1	2	3	4	5
Polarization	Longitudinal wave	1	2	3	4	5
Intensity	Frequency	1	2	3	4	5
Diffraction	Interference	1	2	3	4	5
Intensity	Wavelength	1	2	3	4	5
Longitudinal wave	Interference	1	2	3	4	5
Time period	Wavelength	1	2	3	4	5
SHM	Polarization	1	2	3	4	5
Transverse wave	Diffraction	1	2	3	4	5
Intensity	SHM	1	2	3	4	5
Interference	Transverse wave	1	2	3	4	5
Time period	Interference	1	2	3	4	5
		Less Related				More Related

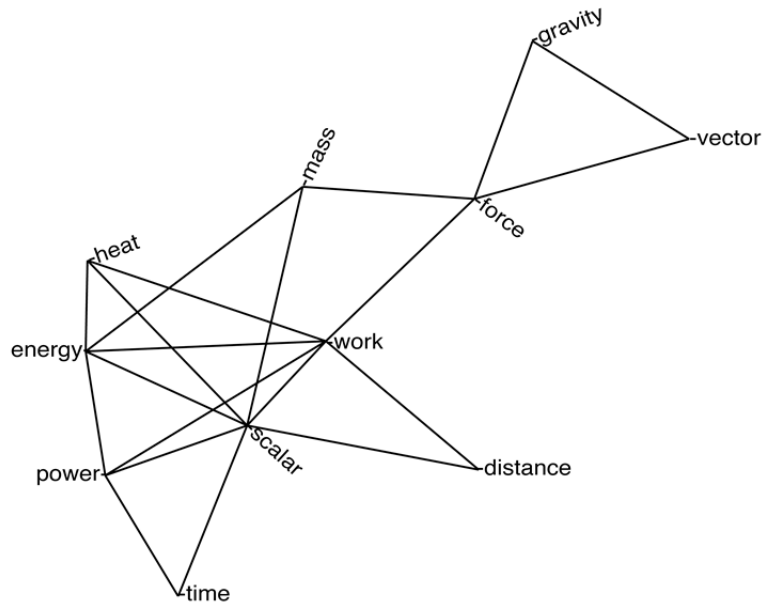
Appendix J: Reflection from the unit “work, energy & power” as Intervention

As shown in Figure J.1(a), the referent PFnet shows that the concept of *work* is related to six other concepts, i.e., distance, scalar, power, energy, heat and power. Let us consider the force concept in the PFnet of the student-48, as shown in Figure J.1(b). The student-48 links the concept of work with only distance, scalar, power, energy and heat and misses the link of work concept with force as compared to work concept in the referent PFnet. This student was given the following instruction for the reflection during intervention:

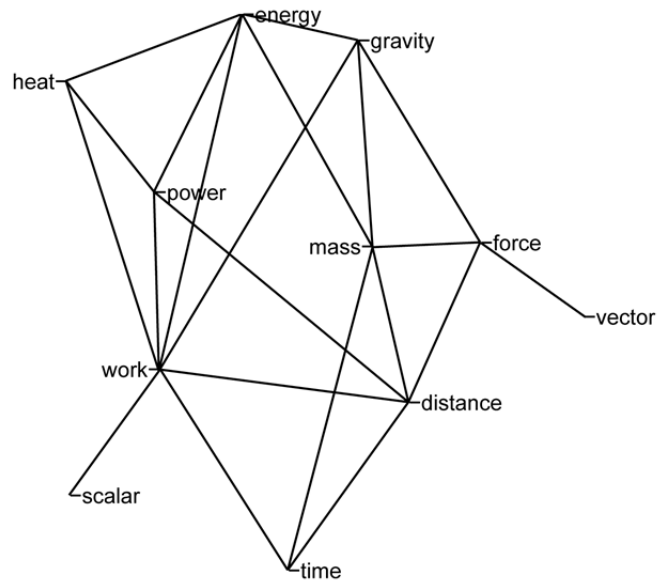
Your ratings indicate that you see the concept of “work” as being relatively strongly related to the concepts of “distance”, “scalar”, “power”, “energy” and “heat”. Many expert scientists think that the concept of “work” is also strongly related to the concept of “force”. Can you think of ways in which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

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

Add the missing links to your Pathfinder network (with a dotted line) that the experts’ averaged Pathfinder network has around the concept of “work” but you don’t, and delete any additional and irrelevant links around the concept of “work” (by crossing them out with an “X”) that you have but the experts’ averaged Pathfinder network don’t.



- (a) The referent PFnet around the concepts of “work, energy & power”. Work concept is picked as a treatment concept.



- (b) Student-48’s PFnet around the concepts of “work, energy & power”. Work concept is picked as a treatment concept to compare it with work concept in the referent PFnet.

Figure J.1

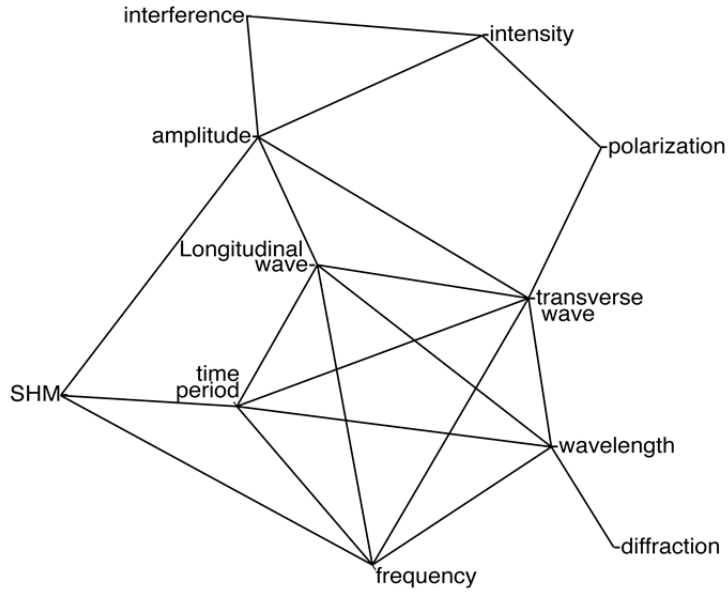
Appendix K: Reflection from the unit “wave motion & nature of light” as Intervention.

As shown in Figure K.1(a), the referent PFnet shows that the concept of *transverse wave* is related to six other concepts, i.e., wavelength, frequency, time period, longitudinal wave, amplitude and polarization. Let us consider the transverse wave concept in the PFnet of the student-182, as shown in Figure K.1(b). The student-182 links the concept of transverse wave with only polarization, amplitude, longitudinal wave and time period and misses the links of transverse wave concept with frequency and wavelength as compared to transverse wave concept in the referent PFnet. This student was given the following instruction for the reflection during intervention:

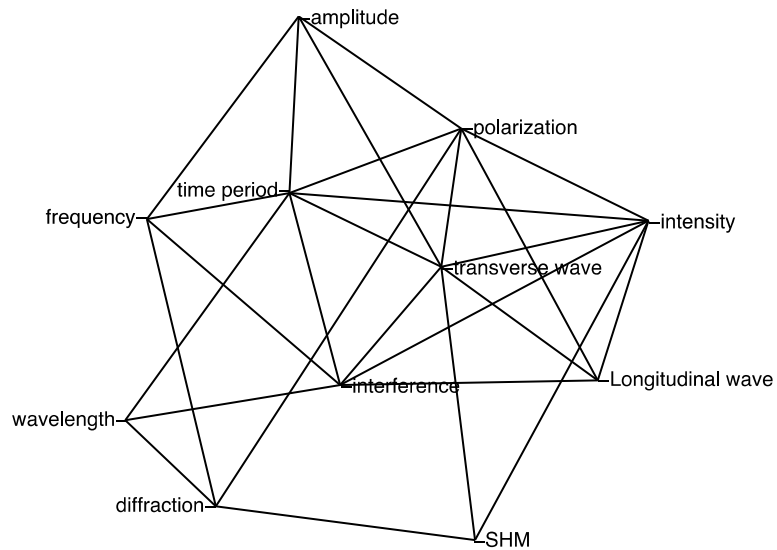
Your ratings indicate that you see the concept of “transverse wave” as being relatively strongly related to the concepts of “polarization”, “amplitude”, “longitudinal wave” and “time period”. Many expert scientists think that the concept of “transverse wave” is also strongly related to the concepts of “frequency” and “wavelength”. Can you think of ways in which “transverse wave” is strongly related to “frequency” and “wavelength”?

Your ratings also indicate that you see the concepts “transverse wave” as being relatively strongly related to the concepts of “SHM”, “interference” and “intensity”. Many expert scientists do not see them as being quite as strongly related. Can you also think of ways in which “transverse wave” is NOT very strongly related to “SHM”, “interference” and “intensity”?

Add the missing links to your Pathfinder network (with a dotted line) that the experts’ averaged Pathfinder network has around the concept of “transverse wave” but you don’t, and delete any additional and irrelevant links around the concept of “transverse wave” (by crossing them out with an “X”) that you have but the experts’ averaged Pathfinder network don’t.



- (a) The referent PFnet around the concepts of “wave motion & nature of light”. Transverse wave concept is picked as a treatment concept.



- (b) Student-182’s PFnet around the concepts of “wave motion & nature of light”. Transverse wave concept is picked as a treatment concept to compare it with transverse wave concept in the referent PFnet.

Figure K.1

Appendix L: Written Exercises from the unit “work, energy & power” as Intervention

As shown in Figure 2.3(b), the referent PFnet shows that the concept of *work* is related to six other concepts, i.e., distance, scalar, power, energy, heat, and power. All students were given written exercises around all the related links (i.e., distance, scalar, power, energy, heat, and power) during intervention. The aim of giving written exercises around all the related links was to develop more knowledge around missing links of students and to enforce their existing links shown by their PFnets. The students were given the following written exercises during intervention:

(a) To develop more knowledge concerning work-power 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 \times distance.
 - (b) energy \times time.
 - (c) work \times 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

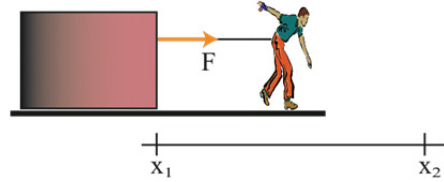
(b) To develop more knowledge concerning work-distance link

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

(c) To develop more knowledge concerning work-force 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 block 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?

(d) To develop more knowledge concerning work-heat & work-energy 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 $g = 10 \text{ m/s}^2$. 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).

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.

(e) To develop more knowledge concerning work-scalar link

4. 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.

Appendix M: Written Exercises from the unit “wave motion & nature of light” as

Intervention

As shown in Figure 2.4(b), the referent PFnet shows that the concept of *transverse wave* is related to six other concepts, i.e., wavelength, frequency, time period, longitudinal wave, amplitude, and polarization. All students were given written exercises around all the related links (i.e., wavelength, frequency, time period, longitudinal wave, amplitude, and polarization) during intervention. The aim of giving written exercises around all the related links was to develop more knowledge around missing links of students and to enforce their existing links shown by their PFnets. The students were given the following written exercises during intervention:

(a) To develop more knowledge concerning transverse wave-time period link

1. The relation between frequency ν and time period T is
 - (a) $\nu = c T$
 - (b) $\nu = \frac{2\pi}{T}$
 - (c) $\nu = 2 \pi T$
 - (d) $\nu = \frac{1}{T}$
2. If the time period of a transverse wave is 4 s, then its frequency is
 - (a) 0.25 Hz
 - (b) 0.25 Hz
 - (c) 1 Hz
 - (d) 2 Hz
3. The product of time period and frequency of a wave is equal to
 - (a) 0.5
 - (b) 1.0

- (c) π
- (d) 2π

(b) To develop more knowledge concerning transverse wave-frequency link

4. A wave generator produces 20 waves in 4 s, its frequency is
- (a) 2 Hz
 - (b) 4 Hz
 - (c) 5 Hz
 - (d) 20 Hz
5. If a transverse wave of velocity c is of frequency ν and wavelength λ , then for a transverse wave of velocity $2c$, the frequency and wavelength could be _____.
- (a) 2ν 2λ
 - (b) $\nu/2$ λ
 - (c) $\nu/2$ 2λ
 - (d) ν 2λ
6. A transverse wave has a wavelength of 2 m. Calculate the frequency of this transverse wave given that the speed of wave is 400 m/s.
- (a) 800 Hz (b) 100 Hz (c) 200 Hz (d) 500 Hz
7. A source of frequency 10 Hz emits waves of wavelength 1 m. How long does it take in order for the waves to travel 600 m?
- (a) 6 s (b) 3 s (c) 75 s (d) 60 s

(c) To develop more knowledge concerning transverse wave-wavelength link

8. Which one of the following pairs of quantities concerned with wave motion can be both

measured in meters?

- (a) Wavelength Frequency
- (b) Velocity Wavelength
- (c) Velocity Frequency
- (d) Amplitude Wavelength

9. With a velocity of 300 m/s, a wave of frequency 1,000 Hz travels between two points P and Q. If the length of PQ is 600 m, how many wavelengths will there be in PQ?

- (a) 3.3 (b) 600 (c) 2,000 (d) 0.3

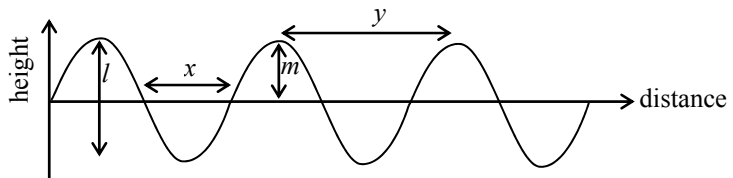
10. The speed of a transverse wave in air is 100 m/s. What is its wavelength if the frequency is 400 Hz?

- (a) 4 m (b) 0.25 m (c) 250 m (d) 40000 m

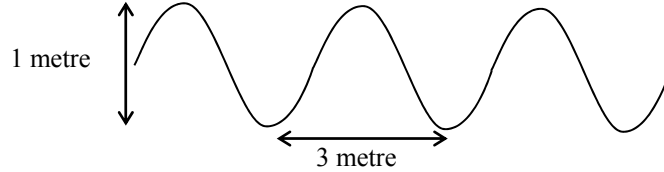
(d) To develop more knowledge concerning transverse wave-amplitude link

11. Below is a diagram that shows the heights and the distance of a train of transverse waves at a given instant. Which one of the following symbols correctly labels the amplitude and wavelength?

- | <i>Amplitude</i> | <i>Wavelength</i> |
|------------------|-------------------|
| (a) m | y |
| (b) x | m |
| (c) y | l |
| (d) l | x |



12. The diagram below represents a transverse wave. What is the amplitude of the wave?



- (a) 2 m (b) 1 m (c) 0.5 m (d) 1.5 m

13. What is the basic difference between transverse and longitudinal mechanical waves?

- (a) a difference in frequency
- (b) a difference in the medium through which they travel
- (c) a difference in amplitude
- (d) a difference in the direction of vibration

(e) To develop more knowledge concerning transverse wave-longitudinal wave link

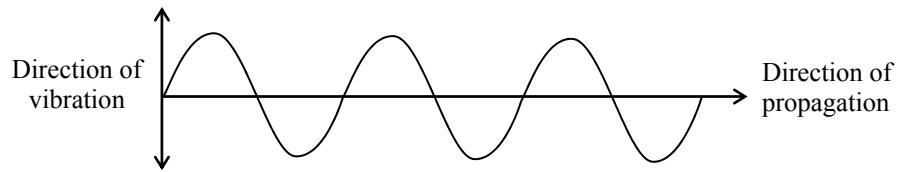
14. What is the basic difference between transverse and longitudinal mechanical waves?

- (a) a difference in frequency
- (b) a difference in the medium through which they travel
- (c) a difference in amplitude
- (d) a difference in the direction of vibration

15. Given the following statements about waves, which one(s) is/are correct?

1. All waves can be reflected.
 2. Only light waves can be refracted.
 3. All waves are transverse in nature
- (a) 1, 2 and 3 are correct.
 - (b) Only 1 and 2 are correct.
 - (c) Only 1 and 3 are correct
 - (d) Only 1 is correct.

16. The figure below is a diagrammatic picture of a simple wave motion.



(a) State whether you can consider the wave to be transverse or longitudinal.

(b) Give a reason.

17. State whether each of the following waves is transverse or longitudinal.

(a) Radio (_____)

(b) Light (_____)

(c) Sound (_____)

(d) Infra-red (_____)

(f) To develop more knowledge concerning transverse wave-polarization link

18. Polarization of light shows that light waves are _____

(a) stationary waves.

(b) compressional waves.

(c) longitudinal waves.

(d) transverse waves.

19. Longitudinal waves do not show _____

(a) reflection.

(b) refraction.

(c) polarization.

(d) diffraction.

(e) none of the above.

20. Polaroid sun glasses decreases glare on a sunny day because they _____

(a) block a portion of light.

(b) are dark in colour.

(c) use a thick glass.

(d) None of the above.

Appendix N: Multimedia Instruction from the unit “work, energy & power” as**Intervention**

All students were given multimedia instruction around all the related links (i.e., distance, scalar, power, energy, heat, and power) during intervention. The aim of giving multimedia instruction around all the related links was to develop more knowledge around missing links of students and to enforce their existing links shown by their PFnets. The students were given the following multimedia instruction during intervention (The multimedia instruction cannot be produced on a paper, therefore, only screenshots of the multimedia instruction is shown here.):

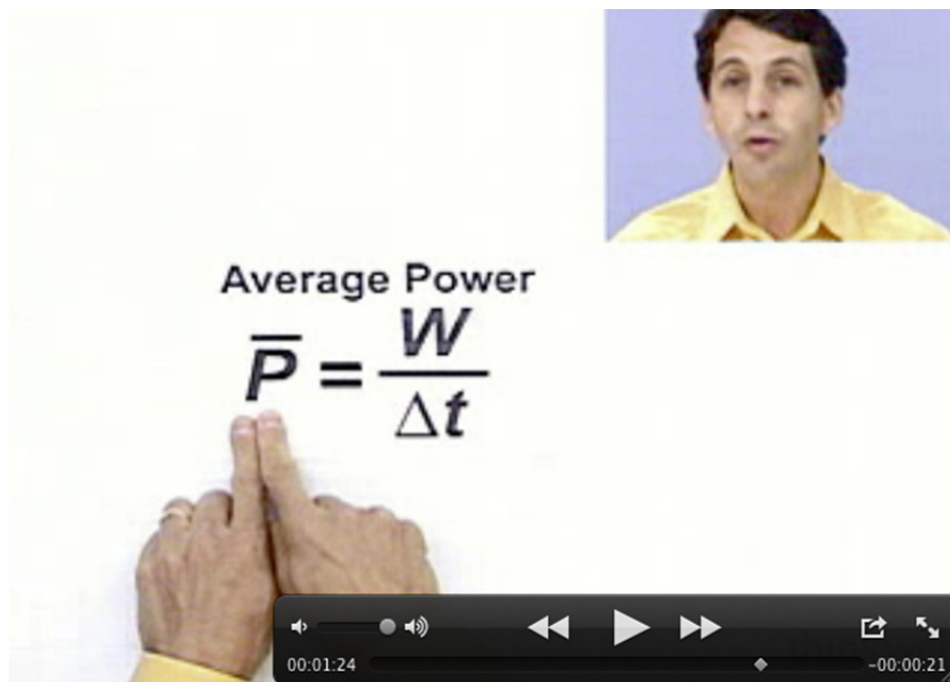


Figure N.1. To develop more knowledge concerning work-power link.

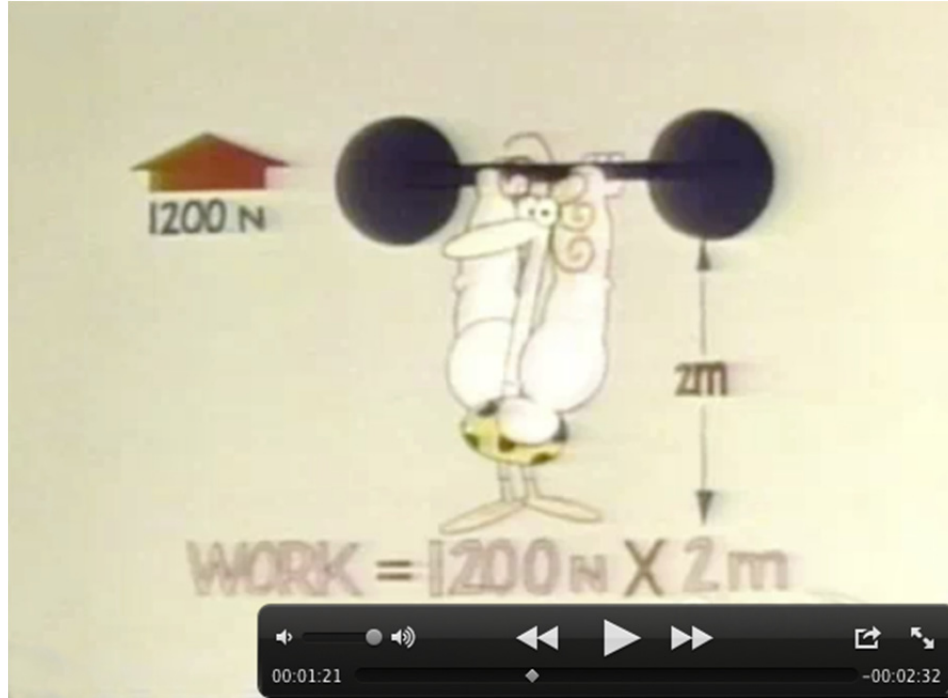


Figure N.2. To develop more knowledge concerning work-distance link.



Figure N.3. To develop more knowledge concerning work-force link.



Figure N.4. To develop more knowledge concerning work-heat & work-energy link.

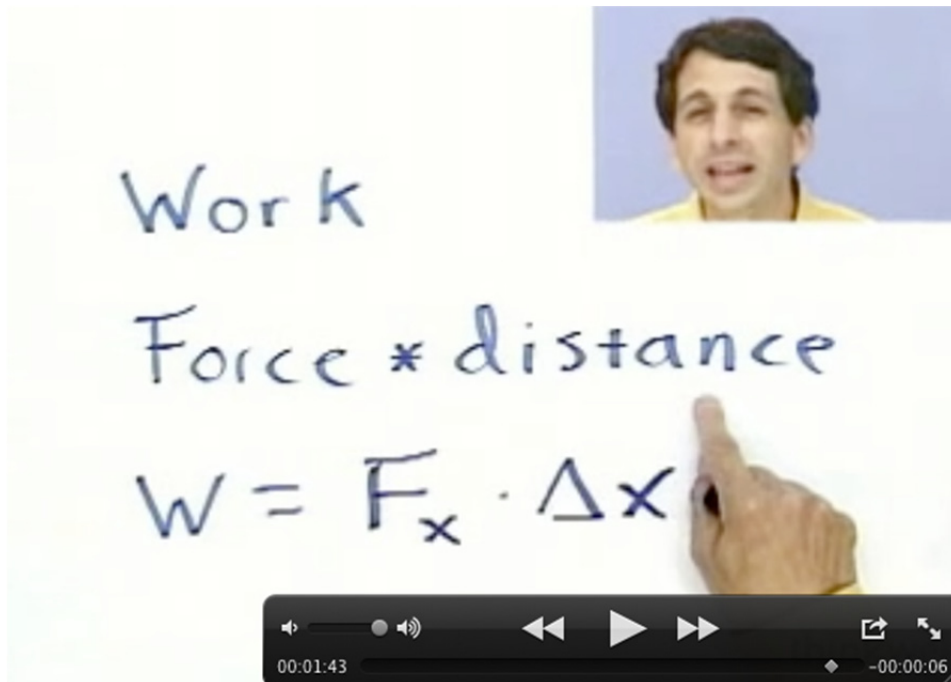
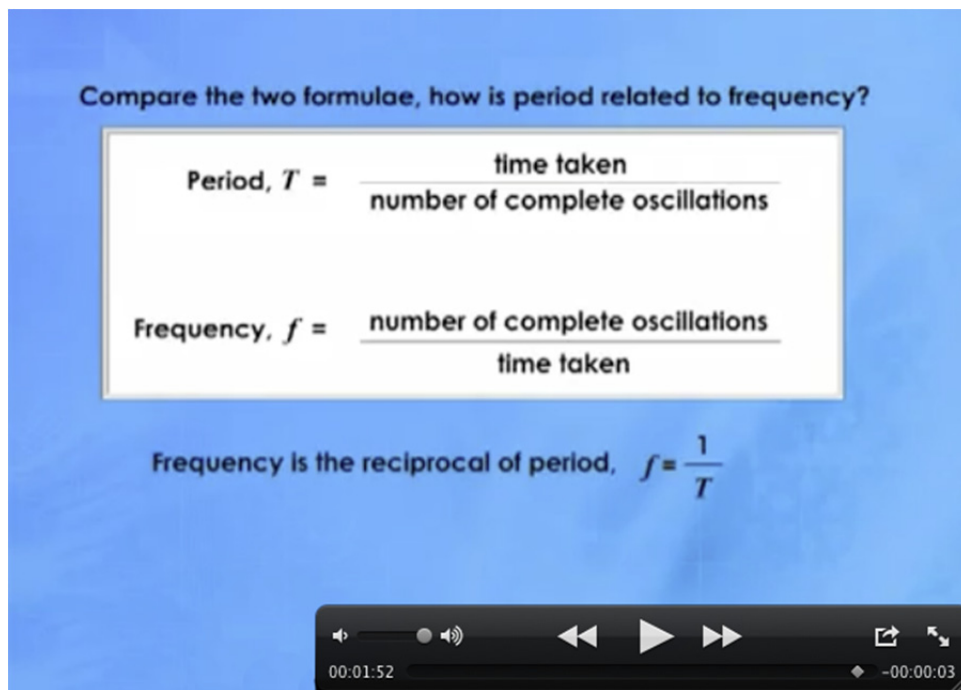


Figure N.5. To develop more knowledge concerning work-scalar link.

Appendix O: Multimedia Instruction from the unit “wave motion & nature of light” as Intervention

All students were given multimedia instruction around all the related links (i.e., wavelength, frequency, time period, longitudinal wave, amplitude, and polarization) during intervention. The aim of giving multimedia instruction around all the related links was to develop more knowledge around missing links of students and to enforce their existing links shown by their PFnets. The students were given the following multimedia instruction during intervention (The multimedia instruction cannot be produced on a paper, therefore, only screenshots of the multimedia instruction is shown here.):



Compare the two formulae, how is period related to frequency?

$$\text{Period, } T = \frac{\text{time taken}}{\text{number of complete oscillations}}$$
$$\text{Frequency, } f = \frac{\text{number of complete oscillations}}{\text{time taken}}$$

Frequency is the reciprocal of period, $f = \frac{1}{T}$

00:01:52 -00:00:03

Figure O.1. To develop more knowledge concerning transverse wave-time period link.

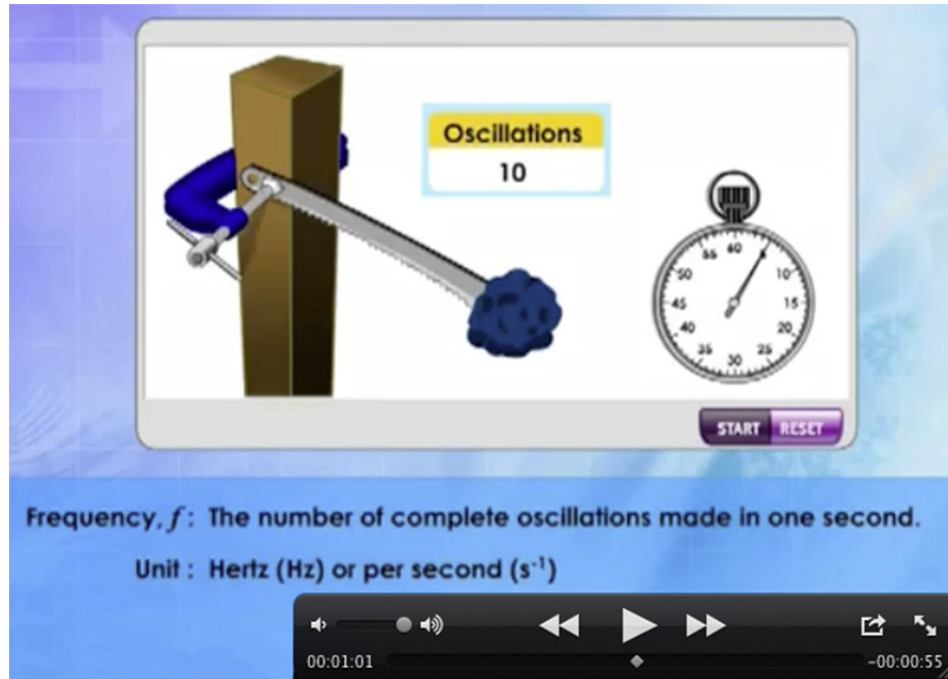


Figure O.2. To develop more knowledge concerning transverse wave-frequency link.

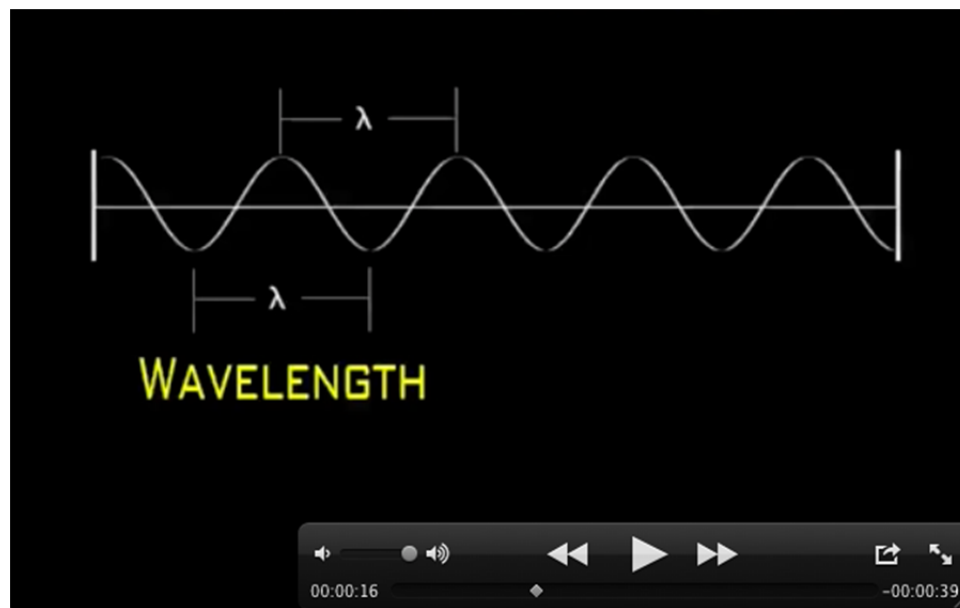


Figure O.3. To develop more knowledge concerning transverse wave-wavelength link.

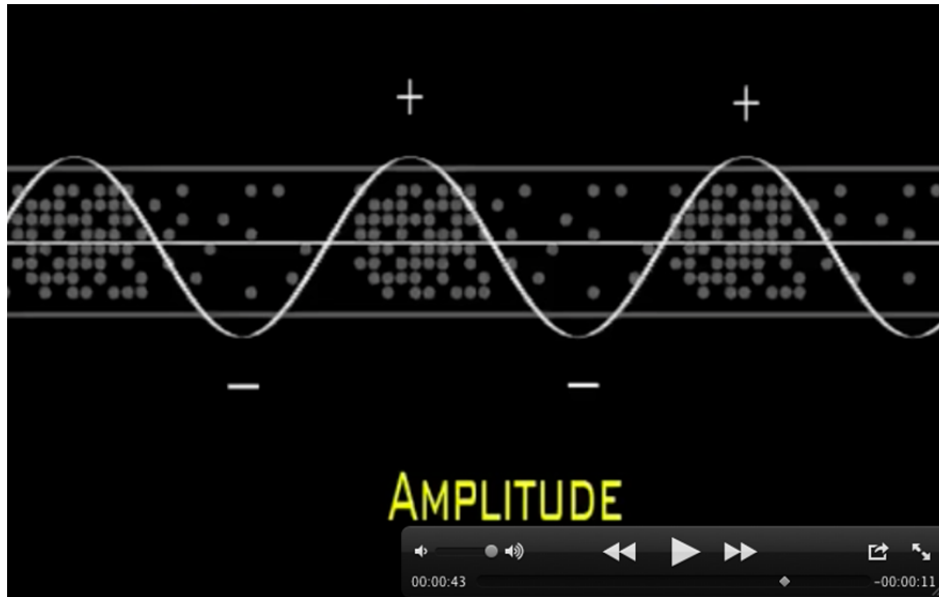


Figure O.4. To develop more knowledge concerning transverse wave-amplitude link.



Figure O.5. To develop more knowledge concerning transverse wave-longitudinal wave link.

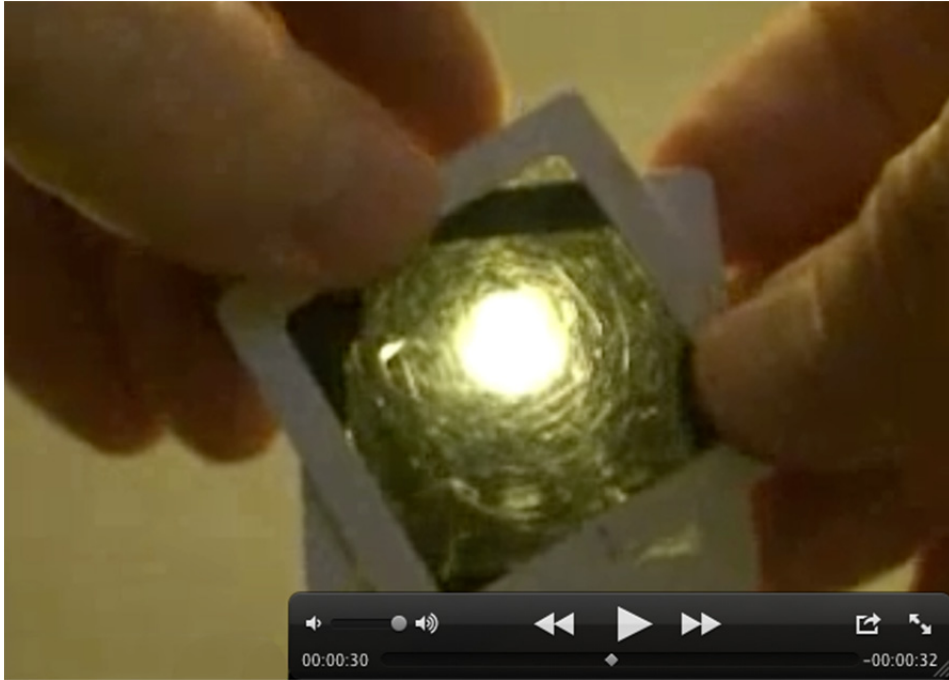


Figure O.6. To develop more knowledge concerning transverse wave-polarization link.