SURVEYING ALTERNATIVE CONCEPTIONS ABOUT ENERGY IN THE CLASSROOM

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ABSTRACT

Secondary school pupils' concepts of energy were probed by clinical interviews and a multiple choice survey administered to 84 Alberta students. Preliminary information was gathered from curriculum documents, misconceptions literature and eight preliminary interviews. Both the interviews and the written survey were based on the interview-about-instances approach and used multiple-choice questions with free-response justification of answers.

The wide range of alternative conceptions that were expressed paralleled findings of similar studies elsewhere. Most descriptions of energy were framed in substantive or ambiguous terms. Energy was frequently associated with living things, movement, and task performance. It was confused with concepts of heat, force, and pressure. Changes in physical systems were seen variously as consuming energy or as producing it upon demand.

Aspects of a scientific conception were more evident among senior physics students, but differences between classes and grade levels did not generally reach statistical significance. Very few responses involved notions of energy as an abstract or conserved quantity. References to energy degradation or dissipation during changes were infrequent in interviews, survey responses, and curriculum documents.

Subjects tended to choose similar responses on parallel interview and survey questions. Interview subjects showed evidence of preferred conceptual orientations towards a variety of situations, although their survey responses showed no parallel

consistency. Conflicting evidence was obtained regarding the spontaneous use of energy-based descriptions of physical situations.

Findings were interpreted from a constructivist stance, and implications for the study and teaching of specific topics were drawn. In addition, results suggested the efficacy of appropriate multiple choice instruments as an alternative to clinical interviews in the investigation of alternative conceptions.

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Chapter 1

Introduction

Problem and Context

Children's ideas about the natural world have a certain intrinsic charm that invites investigation. Systematic exploration of "children's science" dates from the time of Piaget's early work and extends beyond cataloguing childish errors and distortions (Confrey, 1987). Investigators have probed children's thinking about particular science topics, methods of solving problems, and about science itself. A variety of data collecting strategies and interpretive devices have been developed for these tasks (Sutton, 1980). Children's ideas have been shown to exhibit a degree of coherence and persistence which suggests links to underlying structures or conceptual frameworks (Driver & Bell, 1986).

Cognitive researchers have placed findings about children's science into both theoretical and practical contexts. Existing knowledge, they argue, affects the perception and interpretation of new experience in subtle and pervasive ways. In particular, children make sense of school experiences according to their existing stock of images, concepts and cognitive skills (see, for example, Posner, Strike, Hewson & Gertzog, 1982). From this perspective, gaps between children's, teachers' and scientists' images and ideas represent a major pedagogical challenge on several levels (Pfundt & Duit, 1988).

1. Curriculum design: Topics of instruction might profitably be chosen and sequenced in order to build upon naive conceptions which parallel or underlie accepted scientific ideas.

2. Instructional design: Children might need to recognize and express existing ideas before they can be modified or replaced. "Conceptual change" models of instruction take explicit account of childrens' existing ideas and attempt to build upon them (Osborne & Freyberg, 1985). Implementations of these models rely heavily on dialogue and student interaction.

3. Instructional materials: The daily stuff of school teaching - textbooks, discussions, activities, questions - might profitably be built upon common conceptions or misconceptions.

A considerable body of information about children's conceptions of the natural world has accumulated in this "constructivist" tradition. Some teaching methods and materials have been based upon it, but their impact appears to have been more on the rhetoric and appearance of schooling than on the substance of typical classroom interaction (Edwards & Furlong, 1978; Edwards, 1987; Yager & Stodghill, 1979). Observational studies suggest that schooling continues to be overwhelmingly devoted to control, ritual, and transmission of adult knowledge, at least at secondary level in England and the United States (Edwards, 1987; Goodlad, 1984.)

Purpose and Design of the Study

In Alberta, a major revision of secondary science programs is in progress. To unify instruction across topics and grade levels, six themes have been identified: change, diversity, energy, equilibrium, matter, and systems. Perhaps surprisingly, the literature contains virtually no data concerning the ideas of Alberta (or even Canadian) students about these themes or the topics being used to exemplify them. The present study represents an attempt to gather such information about student conceptions of one theme: energy.

The study of energy, which has applications in physical science theory, technology, and current social issues, appears in both past and incoming Alberta science curricula. Unfortunately, investigations from several countries suggest that the study of energy poses considerable difficulty for many students. The concept itself is abstract and easily misconstrued, and popular usage of the term differs considerably from its scientific meaning (Duit, 1984). Teachers, at least in the early grades, may share the misunderstandings held by their students (Kruger, 1990). Validation of these and similar findings in an Alberta context appears to be appropriate and timely.

The study was based on an adaptation of a method outlined by Treagust (1988). Curriculum documents were examined to identify knowledge of the topic which students might reasonably be expected to demonstrate. Common alternative conceptions within this domain were identified from the literature and from eight semi-structured interviews. These preliminary findings were used to construct a survey instrument employing multiple choice questions together with written justification of answers.

The survey instrument was then tested on a larger population of 84 students. Frequency tables were used to compare response patterns of different groups of students. The significance of observed differences in response patterns was estimated using the chi-square statistic. The consistency of individual student's responses across several items was also investigated. Written justifications of responses were analyzed thematically and compared with interview and literature findings. The consistency of responses to parallel items in the interview and survey was established for the eight students who participated in both aspects of the study.

Research Questions

The study addressed five specific questions arising from the existing literature about alternative conceptions.

1. Would misconceptions and alternative conceptual orientations reported in the literature also be evident in interviews and written surveys of Alberta students?

2. Would subjects show a similar pattern of responses to interviews and written surveys? The ease of using written, multiple-choice instruments makes them more suitable than interviews for use on a broad scale or for instructional purposes in classrooms. It is not clear, however, that written instruments can provide similar information to interviews.

3. Would there be noticeable differences in responses between grade 9 subjects, who have not received a formal introduction to energy at secondary school level, and grade 11 subjects, who were introduced to the subject two years previously? Previous studies have shown alternative conceptual orientations to be remarkably persistent in the face of standard classroom instruction (see, for example, Driver and Bell, 1986).

4. Would the proportion of students utilizing a scientific orientation vary between classes? In particular, physics students have been assumed to be more interested and academically capable in science than general science students. They may be expected to have assimilated comparatively more of the reasoning patterns and scientific knowledge presented in previous science courses.

5. Would students consistently utilize a given conceptual orientation? Previous studies have found student responses to be situation-specific and often contradictory. Which conceptual framework to use seems to depend on a variety of cues, not all of which are logically relevant to the particular problem being considered.

Significance of the Study

The present study extended the body of existing knowledge about alternative conceptions of energy to a previously unstudied population: Alberta secondary school students. Additional evidence for the widespread existence and nature of previously-described alternative conceptions was obtained. The majority of responses fit the widely-used categories of alternative conceptions about energy developed by Watts (1983a). Contrary to earlier studies, however, significant differences in response patterns were found to exist between groups of secondary students. This result calls into question the postulated stability of alternative conceptions in the face of school instruction.

A novel view of Watts' categorization of alternative conceptions of energy was developed during the study. Three dimensions of the energy concept were defined and described using Watts' terms. This reinterpretation of previous findings proved useful in analyzing student responses and represents an extension of earlier analyses.

In terms of methodology, the study provided evidence of both the general utility and the limitations of Treagust's method of developing multiple-choice survey instruments. Firstly, the search of curriculum documents produced an unexpectedly large number of primitive factual statements, which greatly complicated the production of a coherent concept map outlining such a broad curriculum area. Secondly, initial fears about student reticence during interviews carried out by their own instructor proved unfounded. Interviews were effective in providing a stock of illustrations and descriptive phrases for multiple-choice questions. Finally, although the survey instrument was able to elicit clear differences in responses between students, it proved extremely difficult to word multiple-choice responses which reflected specific alternative conceptions.

In practical terms, the study has several significant outcomes. Because subjects included the last group of grade 9 students who followed the 1978 Alberta junior high school science curriculum, the study provides baseline data for future studies of the impact of new Alberta science programs. Second, the information about student conceptions of energy has already proven useful to the researcher in his role as high school science instructor. Similar investigations of the other five themes in the new Alberta science programs could provide useful background for teachers across the province.

Finally, the present investigation could be extended to prepare a more elaborate survey for use in classroom instruction or teacher preparation or inservice. Treagust and colleagues have used similar studies as the basis for two-tier objective surveys. These instruments are designed to elicit alternative conceptions by presenting, in multiple-choice form, both a situation to analyze and a number of justifications for the chosen response. The production of suitable items poses considerable difficulties, but their potential ease of use is appealing.

Definitions

Descriptions of children's thought have not, unfortunately, been reported in a standardized vocabulary. Some commonly used terms have an evaluative cast which might best be avoided lest it subtly shade the writer's (and reader's) perception (Abimbola, 1988). Other words have technical connotations in cognitive psychology which may not be immediately apparent and preclude loose or intuitive use. Vocabulary for the present study was chosen after considerable deliberation, which for purposes of clarity is discussed below.

Following Pines (1985), the term "concepts" will be taken as signifying "packages of meaning [which] signify regularities (similarities and differences), patterns, or relationships among objects, events, and other concepts....Concepts are regularities labelled with words and employed in thought and communication" (p.108). Watts and Gilbert (1982) emphasize that concepts are multi-dimensional. Different aspects may prove more useful in particular situations, so a concept may not be displayed with a consistent profile.

Abimbola (1988) analyzed a number of labels used in studies of widespread everyday notions which differ from currently orthodox scientific conceptions. The once dominant term 'misconceptions' clearly locates this research in the enormous body of knowledge about concept formation and conceptual change. This literature is especially fruitful when considering possible pedagogic applications of information about children's ideas.

However, the designation 'alternative conceptions' seems preferable to 'misconceptions' on several counts. 'Alternative' carries no implication of truth or falsity, and is relatively free from implications that student ideas are suitable objects of diagnosis, remediation, benign neglect, or quaint amusement. It does suggest comparison, discussion and choice, all of which are commonly regarded as essential elements of the scientific enterprise. It even allows for the disturbing possibility that students may, as a result of truly scientific investigation, choose to maintain their alternative conceptions rather than adopt the desired scientific view (Erickson, 1983; Watts & Pope, 1989).

Mental activity beyond the level of immediate recognition and labelling of sensation involves relating concepts. Therefore, in Pines' (1985) words,

> "A concept is involved in an immense network of relations. A concept can be thought of as a theoretical point where meaningful relations converge, and each concept is a crossing point for a multitude of relations. The relations are the fibres from which meaning is constructed. No fibre exists in isolation....The fibres are propositions, each signifying a single (or several) conceptual relation(s)." (p.109)

It is possible that conceptual relations form in idiosyncratic, ad hoc responses to situations as they arise. Carey (1986) dismissed this notion as theoretically unproductive and observationally suspect. It appears more fruitful to hypothesize an organized body of stored information which serves as a foundation for interpreting present situations in the light of past experience. Sutton (1980) offered a brief summary of evidence for this position. Furthermore, our memory of past experience is not restricted to isolated specifics: we generalize. Thus, everyday knowledge can be regarded as theoretical in nature, although it is not identical to scientific theory in purposes, criteria, or ideals (Hills, 1983).

Networks of related concepts are frequently called "frameworks". This description conveys several important connotations. Frameworks are organized, so the term invites application of a variety of tools used to study organized knowledge, from cognitive psychology's schema theory to the history of scientific ideas. Furthermore, the linkages implied by the term frameworks need not be limited to the cognitive domain. They may extend to the student's linguistic, cultural, social and emotional worlds. Methodology and theory from all these fields have in fact been applied to the study of student ideas in science.

Similarly, a framework need not involve the strictly logical relations of formal scientific theory. It may, like much literature and everyday thought, be analogic in nature (Bruner, 1986). A broader analysis than is usually applied to scientific theory is thus invited.

On the negative side, "framework" carries a possibly misleading sense of stability. Student ideas and minitheories appear to be formed and modified in response to specific situations. Mental organization appears to be flexible and fluid, not rigid and stable (Millar, 1989; Sutton, 1980). Watts and Gilbert (1982) state that "to have a concept is to have a disposition to organize experience in a certain way" (p. 5). Johansson, Marton, and Svensson (1985) capture a similar sense in their analysis of preferred stances from which a subject views and interprets the world. Unfortunately, their term ("conception") appears wanting, as it lacks any sense of dynamic orientation.

The present study uses the phrase "alternative conceptual orientation" to convey a non-judgemental, fluid view of relations between concepts. Description of alternative conceptual orientations thus implies going far beyond the "highly productive cottage industry" which engages in cataloguing student errors (Carey, 1986, p. 1124). Improved teaching and learning involves probing student responses with considerable sensitivity in order to penetrate superficial variations in expression and grasp the extent of understanding (Hills, 1983; Millar, 1989). In particular, the use of approved scientific vocabulary does not necessarily indicate a scientific conceptual orientation (Osborne & Freyberg, 1985; Schuster, 1983; Viennot, 1983). Altogether, the description "alternative conceptual orientations" is meant as a constant reminder of the need for, and dangers of, somewhat subtle methods of investigation, with the consequent need to interpret findings.

Assumptions

Not all models of education attach importance to students' ideas. "Banking" metaphors describe the transmission of information from an authoritative teacher to an uninformed and accepting student (Freire, 1970). "Medical" models regard student misconceptions as informative insofar as they suggest appropriate remedial strategies (Illich, 1970). However, both Freire and Illich suggest that these approaches are ultimately disempowering, leading to intellectual dependence and passivity rather than active, meaningful learning.

As a basis for science teaching, the banking and medical models have additional flaws (Watts & Pope, 1989). Children's experience in a technological society is permeated by scientific words and artifacts. Students do not approach science classes in ignorance. Nor do they easily relinquish their ideas, as has been noted by virtually every researcher in this field. Thus, it appears that knowledge of student conceptions could be of fundamental value in teaching, a claim that Strike (1983) suggests implies a "constructivist" view of education.

A constructivist model, as outlined by Driver and Oldham (1986), for example, locates the essence of learning in students' efforts to make sense of past and present experience. George Kelly's psychology of personal constructs is often cited as a theoretical basis for constructivist thought (for an outline, see Kelly, 1966/1970).

Here, it is sufficient to note Kelly's stress that knowledge is actively constructed by the learner, unique to the individual and dependent upon prior experience. People do not merely associate experiences, or even discover inherent meaning. They construct meanings using their available cognitive resources: perceptual abilities, mental operations, memories of previous experience, and the interpretive framework of language, metaphor, social patterns and their culture's world view. Knowledge thus gained is embedded in a complex web of cognitive, affective and social influences.

As Millar (1989) pointed out, such a view of learning does not necessarily favour a particular model of instruction. Nor need it spring from a particular epistemological commitment. For purposes of this study, the following specific assumptions, which spring from a constructivist view of learning, will be made:

1. Human beings continuously strive to make sense of their environment.

2. Existing knowledge forms the basis of and influences both perception and subsequent sense-making efforts.

3. An individual's knowledge is organized. Features of the organizing framework can be inferred from careful analysis of responses to specific situations.

4. A variety of reasonable individual interpretations will be made from any information. However, these interpretations are not totally idiosyncratic, as many individuals share common knowledge frameworks.

5. Knowledge does not imply belief. Individuals may use diverse and contradictory knowledge frameworks, depending on their situation and purposes.

Three further assumptions will be made relating to the learning of scientific knowledge. They have no particular relation to constructivist thought, and are:

6. Scientific inquiry proceeds within a developing body of consensual knowledge and interpretive frameworks which are commonly held by scientists. Learning science thus involves both personal experience and enculturation to the current paradigms of the scientific community.

7. Acquainting students with current scientific interpretations is a main aim of school science. This must be done "in a way that neither undermines pupils' confidence in their own abilities to make sense of learning experiences, nor grossly misrepresents scientific ideas" (Driver & Oldham, 1986, p. 110).

8. The most desirable activities in school science are those which embody many aspects of scientific inquiry: acceptable interpretations, fruitful imagery, and characteristic epistemology.

Research Perspective

The study adopted a naturalistic research paradigm to investigate students' understanding of a science concept. Such inquiry is interpretive in nature, and aims at probing beyond the surface of a child's knowledge to determine its personal meaning and unique story (Bloom, 1990a). It recognizes the probability of a multitude of influences upon a child's response to any particular cognitive task. Its practical goal is to understand students' responses from their point of view, in order to facilitate access to a scientific view (Duit, 1990).

Examination of the literature has revealed a great variety of perspectives that have been adopted to study children's ideas about the world. Those which impinge most directly on the study are outlined below.

The organization of knowledge in memory clearly affects the cognitive resources which can be recalled and used in a given situation. It appears necessary to distinguish general knowledge from domain-specific knowledge, which has a decisive influence upon task performance. Eylon and Linn (1988) make the Lakatosian distinction between "core" conceptions and procedures, which are very difficult to change, and "protective belt" knowledge, which is readily altered. More complex models of cognitive structure found in the psychological literature include one (Perkins & Simmons, 1988) which is based specifically on alternative conceptions research. It postulates four interlinked "frames" of knowledge: content (or declarative), problem-solving (or procedural), epistemic, and inquiry.

Other research perspectives provide hints of different linkages in the child's mental world. Lakoff and Johnson (1980), for example, argued on linguistic grounds that language, and thus the knowledge that it represents, is structured metaphorically. Bruner (1990, 1986) took a literary approach, suggesting that over time, knowledge is assembled into stories which function as key mental organizers. Head and Sutton (1985) stressed the importance of affective influences on cognitive structure.

Rather than considering the organization of a child's knowledge, some researchers have focussed on its origins. Claxton, cited in Manuel (1990), postulated a two-tier structure of knowledge. Minitheories arising from immediate personal experience form a foundation of "gut science", on which is erected a cultural superstructure of "lay science", which exists as part of shared vocabulary, experiences and images. Osborne and Wittrock (1985) have extended this model and added a third tier, school science, which is distinct from both the gut and lay levels of knowledge.

Solomon (1983b) emphasized the importance of social interaction in shaping knowledge, but emphasized that it produced a loose, context-bound structure, the "familiar, undemanding clutter" of lifeworld knowledge. Similarly, Bloom (1990a) viewed knowledge in terms of complex "contexts of meaning": interlocked factual knowledge, emotions, values and aesthetics which cannot be represented in a purely logical fashion.

Yet another viewpoint concentrates on finding limits to a child's ability to construct meaning for experiences. Defining these limits, from a Piagetian perspective, means investigating progress through a sequence of mental stages. In contrast, Ausubel (discussed in Novak, 1983) suggested focussing on the number and complexity of conceptually-organized regions of experience, rather than any general cognitive capabilities.

To picture the complex web of influences upon the knowledge we display, Toulmin (1972) suggested the image of a "conceptual ecology". It is the features of this ecology, in a constructivist view, that shape the student's response to learning opportunities. In these terms, the present study has attempted to discern and describe the ecological niches which students create for the orthodox scientific conception of energy.

Chapter 2

Related Literature

Historical Overview

Piaget's work of the 1920's and 1930's can be considered as the beginning of one major strand of research in science education. Using the clinical interview as their research tool, investigators in this tradition probed the nature and development of children's understanding of the physical world. Other research focussed on students' content knowledge of different science topics. A third line of investigation examined knowledge in action, as subjects made predictions or solved problems. By the late 1970's a variety of factual errors and flawed problem solving strategies had been uncovered and were catalogued by Driver and Easley (1978).

Watts (1988) cites two articles as providing major impetus for a second generation of more interpretive research. First, Driver and Easley's (1978) review of the literature urged that children's ideas be considered as reasonable attempts to deal with experience, having their own coherence, power and purposes. Second, large-scale studies of physics students and teachers conducted and originally published in South Africa were reported more widely by Helm (1980). He found misconceptions of sufficient scope and persistence to suggest underlying cognitive structures that resisted conventional instruction. Soon after, the interview about instances (IAI) and interview about examples (IAE) techniques were developed and widely used to explore children's ideas about a variety of specific topics in a sensitive and non-evaluative manner.

Confrey's (1987) historical summary outlines major themes of subsequent research. An extensive bibliography of the literature has been prepared by Pfundt and Duit (1987), while a more detailed cross-section of results and interpretations can be found in the reports of the International Seminars on Misconceptions (Helm & Novak, 1983; Novak, 1987). Recently, major syntheses of research have been prepared to identify promising directions for future study (Eylon & Linn, 1988) and to draw out practical implications for classroom instruction (Osborne & Freyberg, 1985).

Children's Science

Children's descriptions and explanations of science-linked situations have consistently surprised observers who expected some parallel to stereotypically "scientific" language, images or reasoning. And yet, children's conceptions are far from idiosyncratic. Only a small number of meaningful knowledge patterns are found in any topic area, and there are many consistencies across topics (Eylon & Linn, 1988). Much alternative conceptions research has been directed at establishing the distinctive characteristics of "children's science" in contrast to "scientists' science".

Unfortunately, parallel investigations of students' and scientists' conceptions are rare in the literature. Data about scientists is generally drawn from "common knowledge" or secondary sources: curriculum or textbook statements, or the work of historians and philosophers of science. Only a relatively small number of investigations have applied the same analysis to both students and scientists; for example, Lin's (1983) exploration of the culture of physics, Cobern's (1988) study of world views, and Ameh and Gunstone's (1985) test of student teachers.

Furthermore, the majority of studies have used topics from the physical sciences. At best, they can be expected to provide only a limited view of scientists' and children's thought, one which may overlook significant characteristics of the life and social sciences. With those caveats, however, the following synthesis draws from generalizations proposed by Driver and Easley (1978), Driver, Guesne and Tiberghien (1985), and Osborne and Freyberg (1985), as well as particular findings by other researchers.

Explanations. Scientists try to produce a minimum number of decontextualized theories which permit the use of logical reasoning to obtain verifiable answers. Children are satisfied with a variety of different explanations to fit specific situations. They see little need for logical rigor or reduction of inconsistencies, and may propose different explanations for the same phenomena, depending on the manner in which questions are presented. Children see no need to explain equilibrium, preferring to focus on dynamic situations. They tend to associate single features or quantities with prior knowledge on the basis of observable similarity. Scientists, on the other hand, try to explain both change and equilibrium by linking as many interacting features as possible in a mechanistic (cause and effect) or contextual (ecological interrelationship) fashion.

Expression. Children are comfortable using words in an ambiguous, undifferentiated fashion, in which meanings may overlap and shift. Images are drawn from the world of concrete experience. Scientific exposition, by contrast, insists on specific, explicit definition of terms, and produces abstract images and conceptual referents.

Reasoning. Children's reasoning tends to be one-way or causal, and attends to absolute, perceptible elements. Much scientific theory aims at extending perception to identify abstract entities, establishing characteristic descriptive parameters and then describing observable interactions by formal (and if possible, reversible) logical propositions. The propositions are often proportional, involving three elements, and may include mediating variables. Especially in the physical sciences, reasoning is based on componential analysis: breaking a problem into small steps, each of which contributes to the final solution via a clear chain of reasoning. Children more often propose functional relationships (only two variables) based on an informal logic of experience. They approach problems holistically, with no distinction between global and local variables, no explicit binding of variables to numerical values, and few attempts to approach a solution through a series of intermediate results.

Proof. Children tend to ignore distinctions between observation and interpretation and typically see no need to provide evidence for accepted ideas. The scientific enterprise, on the other hand, is based on the primacy of observation and continually tests accepted paradigms against new evidence.

Change. Over time, children's explanations grow in number and in associations. Contradictory ideas are ignored, explained away, or tolerated as alternative opinions about the same subject. Scientists follow the principle of parsimony, aiming at a reduced number of ever more comprehensive theories. They seek to resolve contradictions, if necessary by modifying existing theories.

Context. Children, especially when young, regard the world as animate and even anthropomorphic. They relate to their environment in an affective and personal way, offering egocentric explanations for natural phenomena. Commonsense is accepted as a reliable and adequate tool for reasoning and action. Scientists generally adopt a more distant stance, using methods which seek to transcend commonsense and purely personal viewpoints. Depending on the discipline, the natural world is treated as inanimate or at least possessing characteristics which are clearly differentiated from the human. Aesthetic and intellectual factors supplant emotional identification when testing the adequacy of explanations.

Interests. Children focus on novelty and change, whereas scientists attempt prediction through the discovery of regularity and pattern. Also, the child's explanations are based on and need fit with only his restricted personal and social experience. The scientist's work is enriched by scholarly tradition and paradigms, but at the same time must satisfy the demands of the community of his peers. Scientists, therefore, maintain a high and explicit consciousness of the limitations of their observations and explanations which is absent from children's thinking.

Theoretical Models

General Perspectives

A variety of analytic frameworks, primarily those outlined below, have been used to organize data about children's scientific conceptions. No single one has proven generally effective at integrating observations or suggesting systematic methods of improving science instruction (Claxton, 1986; Confrey, 1987; Watts, 1988).

Cognitive Abilities. Lawson and Thomson (1988) reviewed evidence that ability to adopt scientific frameworks might be related to mental capacity, verbal intelligence (ability to recognize analogies in verbally presented material), cognitive style (field dependence or independence), and Piagetian stage of development. From the latter perspective, they suggested that skill training in formal mental operations might directly improve students' ability to systematically compare alternative explanations of observed phenomena.

Metacognition. Explicit monitoring of the progress of one's own thinking, especially the linkages between concepts, might facilitate conceptual elaboration and comparison of alternative conceptual frameworks. A diagrammatic procedure called "concept mapping" has been developed and taught successfully to adults and early adolescents (Novak, 1983; Novak & Gowin, 1984). Improved test scores have been observed when college teachers employed concept mapping as part of their planning and class presentations (Cliburn, 1986). A similar method called "concept webbing" has long been used for planning early childhood instruction (Levin, 1986).

Epistemology. Students and scientists do not appear to have the same objectives, procedures and standards for the generation and validation of knowledge. For example, Allen, Statkiewicz, and Donovan (1983) observed students who failed to differentiate between observation and interpretation, and described their tendency to exempt ideas which are believed to be true from the requirement of evidence. They noted a good fit between their observations and William Perry's stages of intellectual development, which proceed from belief in single answers confirmed by authority, through acceptance of a multiplicity of views regarded as unverifiable opinions, to relativism that views all knowledge in context. Direct studies of considerable scope and elegance conducted by Kuhn and colleagues (1988) support and extend this observation. Preadolescent students, and many adults, fail to recognize the possibility of alternative views, support theories by elaborating on known examples rather than by seeking evidence, and distort observations to fit their beliefs.

Furthermore, students do not share scientists' view of the provisional nature of theory. Waterman (1983) found widespread student belief in the infallibility of scientific knowledge. This, he pointed out, leads logically to a strategy of learning by memorization, and emotionally to unrealistic expectations that hypotheses can be proven absolutely.

Students might become more comfortable with scientific viewpoints if their attention were focussed explicitly on those beliefs about knowledge which underlie scientific inquiry. Thus Helm (1983) argued the utility of explicit instruction about the epistemological foundations of science, instruction which would go far beyond the usual presentation of the legendary "scientific method". In particular, a graphical framework, the "Vee heuristic" has been developed and used to specify epistemological roots of any study and their interaction with data (Gowin, 1983; Novak & Gowin, 1984).

History. Naive viewpoints often resemble elements of abandoned scientific models. Common views of motion, for example, appear similar to aspects of Aristotelian physics. Although this testifies to the persuasive explanatory power of historical theories, it must be remembered that they were integrated into the intellectual and cultural frameworks of earlier times. The ideas of modern students spring from a different ethos and only mirror the historical development of scientific theory in a fragmentary and superficial way (Lythott, 1983). Nevertheless, study of the history of science has been suggested as a source of ideas for research into possible alternative frameworks and curriculum development (Ben-Zvi, Bat-Sheva, & Silberstein, 1986; Nersessian, 1989; Wandersee, 1986). It can also illustrate the nature of scientific theory and inquiry processes (Hills, 1983), and to this end even the lack of agreement over interpretation of the historical record could be instructive.

Concept Development Theories

Two particular theories which relate directly to alternative conceptions research have been productive in generating instructional strategies and materials. One, conceptual change theory, focusses on the learner's reaction to new ideas and features which might lead them to displace existing conceptions. The other deals with the context within which ideas acquire meaning.

Conceptual change theory. P. Hewson (1981) and Posner et al. (1982) have defined four necessary conditions which must be satisfied before concepts can find a niche with a person's conceptual ecology. The conditions and their implications, which are inventoried in Posner (1983), are:

1. Dissatisfaction with existing conceptions. This implies awareness of both the conceptions and their shortcomings, as well as conviction that minor repairs will not suffice.

2. Minimal understanding of the new conception. The subject must be able and willing to relate it, by metaphor, analogy, or image, to his inner world of existing knowledge. Furthermore, the concept must be related to the outer world of experience, often through prototypical exemplars. A fuller understanding, which would involve links to a wider variety of concepts and more complex images (Kleineman, et al., 1987) can evolve later.

3. Initial plausibility of the new concept. It must be consistent with past knowledge and existing beliefs, concepts, and images of the world.

4. Apparent fruitfulness. The concept must offer explanatory, predictive or problem-solving power.

Several general instructional strategies have been proposed as ways of presenting scientific ideas so that they satisfy all four conditions. According to Osborne and Freyberg's (1985) synthesis, they share three common stages, dubbed focus, challenge, and application. In the focus phase, students explore, clarify and express their view of a concept. The challenge phase consists of considering and testing the views of other students and of scientists. Finally, students apply the scientific view to problems, presenting and debating solutions and evaluating their merits. Considerable teacher input appears necessary to provide extended examples and bridging analogies which extend the new concept to both familiar and novel problems (Brown, 1988).

Osborne and Freyberg have also suggested that a preparatory phase is a necessary preliminary for implementing this type of instruction. In it, teacher and student draw on historical and alternative frameworks research to identify and clarify their own views. In addition, the teacher needs to develop considerable sensitivity to explanatory frameworks which students may hold and express somewhat chaotically. Only then will an instructor be able to facilitate expression and clarification of differing views, help uncover underlying rationales, and sympathetically evaluate the merits of alternative conceptions.

Concept change theory has provided a foundation for development of instructional and teacher in-service materials, notably those produced by the Children's Learning in Science Project (CLISP) in the United Kingdom (see, for example, Needham and Hill, 1987; Scott, et al., 1987). In New Zealand, the Learning in Science Project (LISP) at Waikato University has produced an extensive set of recommendations, background materials and teaching suggestions (see Kirkwood & Carr, 1989; Learning in science project, 1982). However, the effectiveness of these offshoots of the theory is as yet uncertain. Rogan (1988), for example, reported that teaching directed to concept change did not result in achievement gains over other teaching methods. Evidence is lacking, however, on possible benefits in terms of long-term retention, facilitation of subsequent learning, mastery of process skills, affective responses, and changes in underlying cognitive structures.

Some writers have questioned whether adherence to a particular model of learning must lead to a particular sequence of instructional steps. Millar (1989) suggests that there is no logical necessity for such a link. Rather, any teaching method which sparks a personal commitment to reconstructing existing ideas will be effective. Identifying specific topics for which conceptual change teaching strategies are particularly suitable is, in this view, an appropriate direction for future research.

Reflective transformation. Authors such as Hulland (1990) and McClelland (1983) place even more stress on the learner's role in conceptual change. Students must be willing to make the considerable effort of incorporating scientific concepts more fully into their repertoire. A particular kind of dialogue is seen as an essential element in this process, and conversational "language games" are thought to be critical factors in organizing thought, perception and social interaction. From this viewpoint, conceptual change is fostered more by attempts to verbalize perceptions and knowledge than by concrete experience alone (Barnes, 1976). Schon (cited in Hulland, 1990) proposed the term "reflective transformation" to describe the gentle process of encouraging meanings to evolve and concepts to change.

In this view, the character of classroom discourse becomes a critical factor in the analysis of learning. A number of studies have delineated features of actual classroom talk that may hinder the meaningful acquisition of new ideas, including concentration on discipline, management and control, lack of attention to student questions, and teacher dominance in forming hypotheses, conclusions and generalizations (Edwards, 1987; Edwards & Furlong, 1978; Elliott, 1976-77; Goodlad, 1984). The sort of "exploratory talk" needed for active learning, according to Barnes (1976), is characterized by hesitations, false starts and rephrasing. It emerges in the context of supportive relationships which reduce the risk inherent in rearranging old meanings and developing new ones. Similarly, Kelly's (1964) description of the "language of hypothesis" suggests a particular phraseology or "invitational mood" which invites the playful consideration of new ideas, without the risk of definite commitment to them.

Clearly, exploratory talk is a far cry from the usual "transmission and control" mode of classroom operation. It is equally distinct from scientific debate, which relies on logical, precise expression and public criticism as effective methods of exposing error (Lin, 1983). Challenging student ideas is certainly part of teaching, but Dillon (cited in Doll, 1989) emphasized the need to balance it with supportive behaviours.

Within this general view of science education as dialogue, several authors have suggested the pedagogic utility of deliberately exploring a variety of metaphors for scientific concepts (Ortony, 1975; Pratte, 1981; Schon, 1988). A whole new teaching sequence can result, as in Steinberg's (1983) innovative introduction to the study of electric current. As yet, however, experimental studies to determine the effect of incorporating metaphor in written instructional material are few.

Bloom (1990a, 1990b) goes further and proposes exploring, not just semantic and metaphoric links to scientific topics, but their affective content as well. He characterizes alternative conceptions as "context markers" or "triggers" for non-semantic "contexts of meaning". In his view, by elaborating many elements of that context to incorporate scientific aspects, teaching may produce indirectly the very conceptual change which appears so resistant to direct instruction.

This type of speculation exhibits some of the qualities that Doll (1989) has identified as characteristic of post-modern thought. It postulates a complex, web-like structure, is directed toward transformatory change in viewpoint, and suggests that such change is internally produced, rather than imposed upon individuals. Studies based on it and reviewed above are relatively few in number, tend to be small-scale, use naturalistic and interpretive research paradigms, and do not aim at producing prescriptions for instruction. Nevertheless, they offer an orientation, if not a recipe, for effective teaching.

School Science

For most children, school brings the first systematic opportunity to link their ideas to those held by the scientific community. However, even in secondary school and university, few students observe scientists modelling their craft, participate in current scientific inquiry, or explicitly consider the structure of scientific knowledge. Instead, the topics which are studied, the expectations, methods and evaluation of learning, and the school setting bear a close parallel to a ritual initiation (Lin, 1983). For many students, participation in the ritual facilitates neither entry into advanced studies (Yager, Snider, & Krajcik, 1988) nor personal appropriation of scientific methods and findings to everyday life.

> Many undergraduates are not exactly overburdened with a need to have what they learn in science classes be consistent either with other scientific ideas or with their own experience. Somewhere they have gotten the idea that science is allowed to be paradoxical and is not supposed to have anything to do with their everyday experience. (Strike, 1983, p.93)

Core topics in school science generally lie comfortably within the body of well-understood knowledge. Facts are unambiguous, theories are accepted, prototypical problems and solution algorithms have been developed, and above all, correct answers exist. Key epistemological features are distorted, as when "scientific method" is presented as a heuristic of discovery rather than a mode of presentation designed to facilitate challenge and verification (Lin, 1983). Other features of scientific inquiry, like the character of evidence and interpretation, are treated implicitly (Allen, Statkiewicz, & Donovan, 1983). A sense of the unpredictability, incompleteness and systematic scepticism of scientific activity is absent from much instruction.

Instead of ideas, Doyle (1983) proposed that the currency of the classroom is answers. A large proportion of school work consists of completing assigned tasks by providing answers. Students attempt to do this with the least possible risk, which leads variously to reticence in oral work, delaying tactics aimed at obtaining hints from the teacher, or attempts to redirect dialogue to a rote or procedural level. There is little opportunity or encouragement for student views to emerge (Goodlad, 1984), so the actual intellectual goal becomes "to decipher and use the framework presented by the text and the teacher" (Erickson, 1983, p. 42).

Teachers expediently impose comfortably short-term, low-level tasks in order to obtain and maintain the co-operation of a "herd of arbitrary size, interests and abilities" (McClelland, 1983, p. 117). Lortie (1975) has documented the lack of institutional encouragement and personal characteristics which might lead teachers towards innovation or long-term goals for themselves, their students or their programs. More recent studies (for example, Yager & Stodghill, 1979) confirm that even in the face of learning materials which have been deliberately and explicitly structured around alternative instructional models, most science teachers revert to traditionally didactic methods. Ornell, cited in Osser, Durmin & Sorenson (1983), saw this type of teaching-as-one-was-taught as "an implied invitation for kids to circulate among themselves meanings and procedures which get the job done" (p. 109). Rather than extending their use and grasp of scientific meanings, children in such a setting must continue to rely on increasingly inadequate everyday ideas. "Progressive" teachers who have interpreted new teaching models as a variant forms of discovery learning can leave students in a similar position, summarized in Driver's quip that the maxim "I do and I understand" should perhaps be amended to "I do and I become even more confused." Driver (1983) and Smith and Lott (1983) offer detailed critiques of discovery learning.

As a result, most students "play the game" with little personal commitment, their ideas either unexpressed or neglected (Edwards & Furlong, 1978). Knowledge and skills remain firmly embedded within the setting of compartmentalized classroom tasks. Success is not necessarily dependent upon generalization which results in mastery of a body of knowledge, nor upon personalization and deployment in everyday life (Doyle, 1983). Instead, academic success in secondary school is confirmed by passing examinations which consist of representative classroom tasks. The student has little choice in the topic or manner of presentation, social interaction during the examination task is strongly discouraged, and judgement is made by an external authority (the teacher or surrogate). As Lin (1983) observes, such a procedure bears little similarity to the peer evaluation of the scientific community. It seems equally remote from the continual social nudges that confirm or modify lifeworld knowledge. Again, as in its mode of discourse, school science has a mode of transmission and evaluation that is distinct from both the scientific and everyday life. Rather than acting as a link between those two realms, school becomes a third world for students to conquer.

Results of Instruction

Whatever the inadequacies of school science instruction, it clearly has some effect upon students' ideas. Gilbert, Osborne and Fensham (1982) described five theoretical results of instruction, all of which are apparent in observational studies.

1. Naive ideas are undisturbed. Students' use of scientific vocabulary may mask the fact that their everyday ideas have not otherwise been influenced by their classroom experience.

2. Naive ideas are reinforced. Experiences in science class are construed as supporting existing ideas, even if that was not the intent of the lesson.

3. Naive ideas are discarded but not replaced. The student is left confused, without confidence in everyday ideas and without adequate comprehension of scientific explanations.

4. Both scientific and naive ideas are adopted. Students use whichever set of ideas seems appropriate to a particular situation. As a result, the ideas do not conflict, and students typically do not attempt to reconcile contradictions between them.

5. A coherent scientific framework is adopted. Scientific ideas are gradually extended, related to other aspects of student experience, and used fruitfully in everyday life.

Much of the interest in alternative conceptions stems from the apparent prevalence of the first three or four of these outcomes, even though they are not generally considered desirable educational objectives. Scholars have hoped that study of alternative frameworks might suggest more effective methods of modifying or replacing naive ideas with scientific ones. A meta-analysis of experimental studies produced the predictable finding that feedback helps to improve subjects' subsequent task performance (Yeany & Miller, 1983). However, there was no evidence that instruction designed to take account of alternative conceptions was uniquely effective. Another negative result was reported by Griffiths, Thomey, Cooke and Normore (1988), who attempted to key corrective teaching to inferred misconceptions. This proved no more effective than remedial instruction that followed the random order of test items.

The persistence and robust nature of children's specific ideas and inferred alternative frameworks has been noted by virtually all researchers who have tried to change them (see, for example, Driver & Bell, 1986; Champagne & Klopfer, 1983; and Viennot, 1979). Halloun and Hestenes (1985) had to place university chemistry students under intense pressure in an interview situation before lifeworld viewpoints would be replaced by more scientific ones, and then only with reluctance. Similarly, Lin (1983) noted students' reluctance to abandon familiar but non-productive problem-solving strategies for standard physics methodologies. Although mastered in a tutoring situation, the standard methods were apparently not trusted to be effective in other contexts.

When instruction apparently has changed students' thinking, the shift has often been in directions unanticipated by curriculum designers and teachers (Osborne & Wittrock, 1983). New scientific vocabulary has sometimes been adopted to label unchanged ideas (Osborne & Gilbert, 1980). Students confronted with anomalous observations have learned to misperceive, ignore, or explain them away as irrelevant, exceptional, or due to factors other than those under consideration (Kuhn, Amsel, & O'Loughlin, 1988; Posner, 1983).

In general, it has not proven very fruitful merely to tinker with science teaching. Remediation or initial instruction designed to expose the inadequacies of everyday ideas does not ensure the adoption or spur the discovery of more scientific ones. Apparently our objectives or our pedagogy require more radical revision if the present results of science teaching are deemed inadequate (Yager, 1991).

Images and Objectives

One possible summary of the research discussed so far is that it details the ineffectiveness of school science instruction in its task of developing accepted scientific conceptions. However, the universal necessity and desirability of this objective have been questioned, as well as its feasibility. More limited goals may be more appropriate, and information about alternative conceptions may play a significant role in formulating and achieving them.

Value of Lifeworld Knowledge

Solomon (1987) focussed on social factors when suggesting that school instruction must inevitably have only limited impact on student thinking. Most students encounter and employ scientific conceptions almost exclusively in school settings. Lifeworld knowledge is reinforced far more extensively in terms of time, situation and affective involvement. By implication, students who meet scientific frameworks in other socially significant settings might show more fluency in utilizing them. This hypothesis is supported by Osborne and Freyberg's (1985) observation that misconceptions were least stable in students whose parents were scientists.

Lifeworld frameworks are usually adequate for everyday systematic thought and performance of routine tasks. They can be thought of as the basis for automatic information processing mechanisms which handle most of our sensory input (Fisher, 1983). However, even when conscious information processing is required, it need not be scientifically correct to be functional. Kempton (1986), for example, observed that a scientifically incorrect concept of how household thermostats operate led directly to energy conserving usage. Correct concepts led in an apparently logical fashion to more wasteful usage, unless the subject had an unusually subtle grasp of thermodynamics.

Images of Learning Situations

Clearly, there are grounds for believing that science instruction cannot and should not aim at general eradication of non-scientific frameworks. In an attempt to delineate those situations where the attempt is appropriate, Pines and West (1983) borrowed a vine metaphor first suggested by Vygotski (1934/1986). Lifeworld knowledge is pictured as growing up from personal experience. Formal (school) knowledge grows down and is imposed from someone else's reality. Concept learning becomes the intertwining of the two vines. The four ways in which this can happen define four domains of instruction, which have distinctive objectives and forms of instruction.

1. Both forms of knowledge may be congruent. There is no conflict, and the learner's task is to extend his limited personal experience into the more extensive scientific framework. Instruction needs to focus on articulating and expanding personal frameworks, rather than challenging them. Aspects of biology are offered as examples of this type of situation.

2. Only lifeworld ("folk") knowledge may exist. No relevant formal instruction has been given. Alternative conceptions research largely ignores this domain, which likely exerts a powerful influence on student thought. Studies of student epistemologist and images of scientists and their activities are important exceptions.

3. Only formal, school-generated knowledge may exist. Topics in this domain are not required or encountered in everyday life. They may be heavily symbolic or taught through pseudo-examples which are as remote from life experience as the topics they are supposed to illuminate. Non-classroom reality checks are not possible (Kass & Fensham, 1990). The instructional task is to convey scientific concepts clearly and understandably. The limited metaphors, images and symbolism that are initially utilized may later have to be modified or replaced, so in a sense they represent misconceptions, but according to Pines and West, there is no need for modification until they begin to inhibit performance or subsequent learning. Much of introductory organic chemistry or particle physics falls in this category of learning.

4. There may be a conflict between formal and lifeworld knowledge; or, in Hills' (1983) terminology, a tension between scientific and commonsense theories. Both offer explanation of phenomena, but with differing perspectives, objectives and epistemologies. In school, students are expected to show some allegiance to the formal concept or their instruction is deemed to have failed. Only in this conflict situation do Pines and West recommend teaching strategies which induce conceptual change.

Science Education

In light of these considerations, Osborne and Freyberg (1985) have formulated a three-tier set of objectives for science education. They suggest that all children should be encouraged to investigate things, explore how they behave, and develop explanations that are sensible and useful to them. Many children, especially in our technological society, must recognize that scientists investigate the world in ways that are sensible, useful, and broadly applicable. To this group, scientific explanations will be intelligible, plausible, and of social (if not direct personal) utility. Finally, some children should move towards accepted scientific explanatory frameworks and a personal commitment to extending scientific knowledge.

Teachers are more able to work towards these goals, according to Osborne and Freyberg, when they are clearly aware of alternative conceptions of topics they attempt to teach. They need materials to clarify their own views, which may resemble the conceptions of their students more than the scientific approach they are expected to teach and model (Ameh & Gunstone, 1985). They must have a firm grasp of current and past scientific views, so they can perceive opportunities to nudge students towards them. Finally, they need tools and skills for eliciting and clarifying student views, and a respect for their logic and utility.

Summary

Systematic investigation of children's notions of the world dates from the early 1920's. On many topics, children express a limited number of alternative conceptions with a character and content distinct from orthodox science and school experiences of science. Not bound by logical rigor, children's science is expressed in a loose, holistic, concrete fashion, paying more attention to experience than proof. It tends to be an animistic, personalized conglomeration rather than the scientist's abstract and parsimonious systems. These and other features of children's science have been linked to cognitive and metacognitive abilities, epistemological commitments, and historical development of scientific thought.

The task of developing scientific notions from preexisting alternative conceptions is taken as a fundamental pedagogical problem by instructional methods based on conceptual change theory and reflective transformation. School science as generally practiced neither elicits nor acknowledges students' alternative conceptions, nor does it model or include actual scientific investigation. As a result, alternative conceptions persist, providing a generally functional, if not scientifically orthodox view of the life-world. A reasonable goal for science education might therefore be to lead children towards an appreciation of, and for some, an acceptance of, scientific conceptual orientations.

Chapter 3

Method

Background

A review of research methods used in previous investigations of alternative conceptions was undertaken before the design of the present study was finalized. Important findings are summarized below.

Research Methods

Inferences about the existence and features of students' alternative conceptions are based on a wide range of observational data. The limitations of early approaches were summarized by Sutton (1980), and methods of enhancing reliability and validity have been proposed by Hoz (1983).

Tasks

Straightforward attempts to catalog some part of a subject's mental database have commonly used lists of statements or beliefs to be judged as true or false. The degree of scientific knowledge or the prevalence of various beliefs or belief structures has then been estimated for the population as a whole (for example, Trembeth, 1984). This type of task does not probe subjects' comprehension or interpretation of the stimulus statements, or the way in which their knowledge is structured.

Research based on word association and word definition tasks (for example, Duit, 1984; Solomon, 1983a) also investigates what Sutton (1980) called "static aspects of the library" (p. 118). However, it probes organization as well as content knowledge. Subjects have been asked to provide word and image associations for a given term, to write free-response definitions, to select from alternative definitions, to rank terms on semantic dimensions such as passive-to-active, to explain resemblances and differences, and to identify exemplars of a concept. Refinements of this sort of task such as the Semantic Differential Test and the repertory grid technique have seldom been used in alternative conceptions research. Alternative methods of exposing linkages between students' ideas include preparing concept maps (Novak & Gowin, 1984) and essay writing (Brumby, 1984).

A large body of research examines the deployment of knowledge in order to make sense of novel situations. Subjects have been asked to describe and/or sketch situations (Griffiths & Preston, 1989; Hulland, 1990), to make and/or explain predictions about the behaviour of objects (Halloun & Hestenes, 1985; McCloskey, Caramazza & Green, 1980), and to solve problems (Hoz & Gorodetsky, 1983). Student progress through instructional or remedial units of study has been tracked with computer (Browning & Lehman, 1988) and without (Smith & Lott, 1983).

Stimuli

The majority of studies reviewed have employed written presentation of problem situations to students. Accompanying diagrams are common, and in the case of Osborne and Gilbert's (1980) widely used interview-about-instances (IAI) procedure, form the core of the problem presentation. Kleineman (1987) and Wheeler and Hill (1990) have noted that in textbooks, even the use of simple and conventional diagrams may introduce unanticipated problems of interpretation. Whether diagram interpretation represents an actual confounding variable in alternative frameworks research has not, to the writer's knowledge, been investigated.

A small number of studies have used teacher demonstrations of problem situations to entire classes (Lawson, 1978; Tobin & Kapie, 1981). Alternatively, students can be taken out of the class and placed in an environment of interest (Bloom, 1990a; Hulland, 1990). Powell and Hoffman (cited in Lawson, 1978) set up lab apparatus for individual students, who worked according to an accompanying booklet of directions and questions. Manipulation of concrete apparatus has also been allowed in clinical interviews (Wheeler, 1983; Gair & Stencliffe, 1988).

Hoz (1983) has argued the necessity of basing any investigation on several tasks which employ different stimuli. In his own interviews, he employed concrete objects, diagrams, and verbal descriptions and explanations attributed to other students. The variety of stimuli and tasks were designed to increase subjects' engagement and encourage complexities of thought to emerge, a process which might be masked by more restricted research designs.

Probes

Some common research designs offer no opportunity for probing a subject's responses. Such investigations may reveal alternative conceptions which produce unusual or ineffective responses but will fail to detect non-standard reasoning which produces acceptable conclusions (Karrquist & Anderson,1983). Furthermore, absence of response probes does not permit any check that subject and researcher share a common understanding of words and symbols. Thus, reliance upon a subject's initial responses forces one to assume that careful task design and the researcher's interpretive skill can provide clear, accurate descriptions of students' thinking (Duit, 1983b).

Clinical interviews offer more freedom to explore and confirm the meaning of responses and linkages between them (Schuster, 1983). They can also be used to reveal the development of thought in a problem situation (Sutton, 1980). Because they are such a widespread source of raw data, interview procedures have been subject to considerable methodological scrutiny. It has become clear that the interview setting is extremely reactive. Seemingly tiny variations in sequencing and formulation of questions may have a clear influence on responses (Viennot, 1983). However, attempts to increase reliability by using a very tightly structured interview format risk losing the flexibility that is the clinical interview's main advantage.

Guesne, Sere, and Tiberghien (1983) have pointed out a related dilemma. Open questions, in which the interviewer gives no cues to appropriate responses, may fail to evoke answers which actually lie within a subject's repertoire. However, closed questions, which suggest a particular type of response, may result in the suppression of alternative conceptions, especially if the subject wishes to please the interviewer.

Such dilemmas appear in principle to be incapable of resolution. In relatively unstructured situations, the interviewer's care, restraint and sensitivity would seem to be the main defense against production of unduly distorted information. Hoz (1983) has pointed out the particular need to avoid qualitative questioning about topics which students have studied in a largely quantitative fashion. Guidelines and procedures for conducting and interpreting interviews have been prepared by Osborne and Freyberg (1985, Appendix "A") and Schuster (1983).

Another method of probing student thought utilizes objective or semi-objective written questions which require both a response and a justification. The latter can be a written statement (Lawson, 1978; Tobin & Capie, 1981) or a multiple choice response (Halloun & Hestenes, 1985; Treagust, 1988). Multiple choice alternatives have generally been prepared from the results of preliminary free response instruments, a procedure first suggested by Tamir (1971). As with clinical interviews, the wording and sequence of questions and possible responses may exert a great influence upon student performance (Fisher, 1983; Guesne, Sere, & Tiberghein, 1983).

Data Recording

Many studies rely on questionnaires and written responses. Interviews have been videotaped (Smith & Good, 1984), but the usual practise has been to prepare annotated transcripts from audiotapes (Gilbert, Watts, & Osborne, 1985). Think-aloud protocols are common in studies of mathematical learning, but have only been used occasionally to investigate conceptions in science (for example, Tolman, 1982). Conversational probing of a subject's strategies and actions by an interviewer is more common.

Interpretation

The majority of studies reviewed are descriptive in nature and do not propose or attempt to confirm hypotheses. The exceptions, which include studies by Fisher (1983), Griffiths and Preston (1989), and Wandersee (1983), utilize only the most basic statistical tools for prediction and confidence checking. Gilbert, Watts, &

Osborne (1985) argued that statistical checks of reliability and validity are largely inapplicable in descriptive/interpretive research, and Schuster (1983) proposed methodological safeguards in their stead.

Many investigators do attempt classification of responses and comparison of their frequencies. Some studies utilize categories established on theoretical grounds (Duit, 1984) or according to prevailing scientific views (Cobern, 1988). Others allow categories to emerge from the data, either in an intuitive fashion (for example, Johansson, Marton, & Svenson, 1985), by using semantic networks (Watts, 1983b) or through other systematic methods of data reduction (Hoz & Gorodetsky, 1983).

Generalizations from the data have been drawn at several different levels:

1. Shared surface meanings for scientific words, and the extent of factual knowledge within a population, have been estimated from word association and definition studies. Although limited in depth, some conclusions have been substantiated in a variety of contexts, and thus appear to be robust clues to deeper meaning structures (Duit, 1983a).

2. Commonly occurring frameworks which individuals use to organize their conceptual knowledge have been inferred on the basis of direct probes of linkages between words, images and ideas. Attempts have been made to clarify both logical and metaphoric connections within these alternative conceptual frameworks. Again, findings show a stability over time and between individuals which gives some confidence in this level of analysis, despite difficulties in obtaining and interpreting interview data (Osborne & Freyberg, 1985). Recent efforts to apply ANOVA

techniques to this analysis lend further support to the notion of conceptual frameworks (Boyes & Stanistreet, 1990).

3. Typical ways in which individuals represent and solve problems have been investigated for a few topics, largely in the physical sciences. This knowledge-in-action exhibits little stability and appears sensitive to a variety of contextual variables, characteristics which have so far prevented general conclusions (Head & Sutton, 1985). Marton (1988) has argued that prolonged consideration of a subject's responses in a variety of situations can lead researchers beneath superficial variations to the discovery of recurrent underlying relationships between the subject and the world. The appropriate mode of investigation is intensive and interpretive, rather than extensive and analytic. Nevertheless, according to Marton, such "phenomenographic reasearch" can result in descriptions of "conceptual orientations" which are able to be generalized beyond particular subjects and situations.

4. Subtle and pervasive cultural influences upon perception and thought have been outlined by investigations adopting world-view and anthropological perspectives (Cobern, 1988; Lin, 1983). These studies provide the least certainty and the greatest degree of abstraction from observed data.

__Summary__

Alternative conceptions research has gone beyond cataloguing knowledge and misconceptions to more interpretive exploration of the meaning, linkages, and functionality of children's ideas. In general, recent research has favoured the use of a variety of verbal and concrete stimuli in interview settings. Subjects' ideas are probed in order to establish the actual sense in which words are being used. Responses are inter-related rather than analyzed in isolation. Studies have been largely descriptive in nature, with small sample sizes and non-statistical analysis. The theoretical constructs of concept, conceptual framework, conceptual orientation, and world view have been applied to the data.

Overview of Study Design

A major purpose of the present study was to establish whether Alberta students display previously identified alternative conceptions of energy. For the sake of parallelism with significant earlier studies, an interview-about-instances approach was adopted. However, to maximize opportunities to explore conceptual linkages, question structure and content was deliberately varied. A number of approaches used or suggested by earlier investigators were incorporated into the interviews and survey: totally free response; open response cued in terms of energy; consideration of the presence of energy; and description of energy changes. All situations were presented diagrammatically, but to increase interest and engagement, concrete stimuli accompanied them when possible, as suggested by Hoz (1983).

A second focus of the study was to establish the practicality of survey-type investigations of alternative conceptions in a classroom setting. Methods of presentation such as demonstrations by an instructor or on videotape or computer were considered to be unnecessarily complex for an initial exploration. Written instruments were therefore developed to serve as stimuli for the survey and the interviews.

Multiple choice questions with an opportunity for open-ended justification and explanation of responses were chosen as providing an opportunity for both interpretive and statistical analysis. To ensure face and content validity of items, they were based on an initial survey of relevant Alberta Education curriculum documents, supplemented by a review of previous research into conceptions of energy.

Analysis was planned to test the widest possible range of previous findings, excepting the early word-association studies of Duit and colleagues. Given the wide variety of common and scientific connotations of the word "energy", adopting single words as the unit of analysis seemed likely to lead to misinterpretations, a point acknowledged by Duit himself in more recent studies (1990). Instead, sentences and entire statements were examined and classified by the concepts they reflected. For interview subjects, the entire transcript was reexamined for evidence of preferred or recurrent conceptual orientations. To keep the study within practical bounds, no attempt was made to generalize to the level of cultural characteristics or world views.

Potential items for the interview and survey were developed in parallel, to facilitate exploration of consistencies of response in the two settings. No sophisticated statistical analysis was considered appropriate, given the small number of interview subjects and the variation between items in this sort of exploratory study. Nevertheless, it was hoped to establish a basis for further investigations using more refined and sharply focussed instruments.

The detailed procedure of the study (Table 1) followed steps outlined by Treagust and colleagues (1988), who employed an interview and survey technique as a first step in developing more sophisticated, two-tier multiple choice survey instruments to investigate alternative conceptions. A very similar item development and interview procedure outlined by Gilbert, Watts, and Osborne (1985) also shaped the interview phase of the present study.

Table 1. Procedural Outline

1. Define content		
	1.1	examine curriculum documents for statements about energy
	1.2	construct a list of factual propositions about energy
	1.3	define concepts underlying and relating the factual propositions
	1.4	validate content knowledge base
2. Explore alternative conceptions		
	2.1	examine literature for identified alternative conceptions about energy
	2.2	construct interview/survey items based on knowledge base and embodying alternative conceptions
	2.3	conduct clinical interviews
	2.4	transcribe and analyze interviews
3. Develop and apply survey instrument		
	3.1	refine items based on interview findings
	3.2	administer survey instrument
	3.3	analyze survey results
	3.4	compare interview and survey responses

Defining Content

Construct Knowledge Propositions

Topics probed by the interview and survey questions were drawn from those prescribed in the Alberta science curriculum. By so doing, it was hoped to ensure that all subjects would have been exposed to a scientific discussion of the questions, as well as to everyday, lifeworld ideas and experiences. Curriculum statements also suggested the depth of scientific knowledge which could be expected from secondary students, and thus aided in the construction of alternative multiple-choice responses.

In this phase of the study, 131 factual statements about energy drawn from current Alberta Education curriculum documents were amalgamated into a restricted list of 28 factual propositions, which is reproduced below (Tables 2a and 2b). Because of the large number of energy-related curriculum statements, it was not considered necessary to follow Treagust's method exactly and examine textbooks or supplementary references for additional material. Similarly, although a tentative cognitive map was constructed to relate the curriculum statements, their number and extent made the map extremely complex and cumbersome. Although its creation may have helped crystallize the investigator's ideas, the actual map was less useful than traditional specification grids when the content validity of the interview and survey instruments was being checked. Therefore, the map was not refined and is not reproduced herein.

Table 2a. Coding of Curriculum References

E: elementary science
J: junior high science
B: senior high biology
C: senior high chemistry
P: senior high physics
G: science 14/24

1. Numbers reference those of the 131 curriculum statements which underlie the proposition.
2. Lettered propositions are drawn from a single senior high school course. As they would not have been studied by all students in the sample, they were not used to construct items for the interview or survey.

Table 2b. Propositions about Energy as a Definable Quantity

1.	Energy is the ability or capacity to do work or cause motion.	J, P	1, 2, 5, 8
2.	Energy is involved in every change in matter.	E, P	3, 4
3.	Energy enables organisms to carry out activities in order to sustain life.	J	6
4.	Energy can be measured in quantitative terms.	P, G	16-20
5.	Heat is a measure of the total energy content of a substance due to its molecular motion.	J, P	12-15, 131
6.	Temperature is a measure of the average kinetic energy of the molecules of a substance.	J	10, 11
a.	Efficiency of an energy system can be calculated.	G	21, 23, 24
b.	Personal energy consumption can be determined.	G	22
c.	Kinetic energy is equal to $mv^2/2$.	P	7

Table 2c. Propositions About Energy Forms and Conversions

7.	Energy exists in many forms.	E, J, P, G	26 -30
8.	One form of energy may be changed into another.	J, G	44, 52-60
9.	Energy may be described as either kinetic or potential.	J, P, G	62-65, 129, 130
10.	Electricity is a form of energy that can be transmitted through a variety of materials.	E	31-33
11.	Sound is a form of energy produced by vibrating objects.	E, G	34, 35
12.	Light is a form of energy.	E	36
13.	Heat is a form of energy produced in predictable amounts from other forms of energy.	J, G, P	37-43, 45

14.	We obtain energy from the food we consume.	J, B, G	46, 47, 110-114
15.	Radiant energy from the sun is converted into heat and chemical energy on earth.	J, B, G	48-51, 61, 128

Table 2d. Propositions about Energy Transfer

16.	The sun is the primary source of earth's energy.	E, J, G	97-99, 78
17.	Energy flows through the biotic world can be traced and are non-cyclical.	B, G	95, 96, 100, 101
18.	The addition or removal of heat energy causes matter to change temperature or state.	E, J	102-104
19.	Chemical changes generally involve more energy than physical changes to the same amount of matter.	E, J, G	105-107
20.	Heat energy flows from areas of higher temperature to areas of lower temperature.	J, G	117
21.	Heat energy is transferred by convection, conduction, and radiation.	J, G	115, 118-126
d.	Energy is transferred in collisions.	G	127
e.	Energy is transferred by waves.	P	89-94
f.	Dissolving involves energy changes.	C	108

Table 2e. Other Propositions about Energy

	Conservation		
22.	Heat lost by one body is gained by another.	J	66, 67
23.	Kinetic energy is conserved in collisions.	P, G	68, 69
24.	The total energy of a system is conserved.	G, P	72-76
g.	Not all systems conserve mechanical energy.	P	70
	Degradation		
25.	In changes in matter, some energy is lost to our use.	E	77
	Husbanding		
26.	Humans are capable of regulating their use of energy.	E, G	79-81
27.	Intensive energy use by man has resulted in changes to the environment.	E	88

28.	Conservation of energy and development of alternative energy sources are essential to our future well-being.	E	86, 87
h.	There are renewable and non-renewable energy sources.	G	82-85

The propositions listed above outline a knowledge base about energy which is taken to be scientifically acceptable, significant, and considered by curriculum and teaching materials designers as appropriate for Alberta secondary school students. Table 3 shows the distribution of statements about energy across grade level and discipline.

Table 3. Distribution of Core Curriculum Statements about Energy

Level	Aspect						Total
	Abstract quantity	Form	Transfer	Conserve	Degrade	Husband	
elementary	1	7	4	0	1	4	17 (13%)
junior high	11	12	11	2	0	0	36 (27%)
biology	0	4	2	0	0	0	6 (5%)
chemistry	0	0	1	0	0	0	1 (1%)
physics	6	7	6	4	0	0	23 (17%)
general science	8	19	10	5	0	6	48 (37%)
totals	26 (20%)	49 (37%)	34 (34%)	11 (8%)	1 (1%)	10 (8%)	131

As a result of their elementary school studies, all Alberta students should have been exposed to the idea that scientists identify certain common phenomena (light, heat, sound) as forms of a more general quantity called energy. Energy is described as moving from place to place. Fuels are sources of energy. Energy needs to be husbanded, because the fuel resources that supply it are in limited supply. Ultimately, the earth's supply of energy can be traced to the sun.

In junior high school, heat and mechanical energy are studied in grade 9. Mathematical calculation of work and energy is introduced. The 1978 curriculum (which at the time of the study had been followed by all interview and survey subjects) includes no mention of energy degradation or husbanding.

Senior high biology and chemistry curricula to grade 11 level make almost no reference to energy. The study of chemical energetics occurs in grade 12. Grade 11 physics follows a historical development of the notion of conservation, so mechanical energy, both kinetic and potential, is introduced quantitatively. Again, none of these courses focus on energy degradation or husbanding.

The general science curriculum being followed by students in the study (Science 14/24) was introduced in 1989. It contains a large number of statements about the scientific conception of energy and about energy husbanding. The treatment is largely qualitative and practical, concentrating on everyday instances and application. However, because the selection of units is left to the teacher, students may not be exposed to these topics.

At the time of the study, greatly revised science programs were being introduced at junior and senior high level in Alberta. In them, energy is used as one of six unifying themes across topics and grade levels. Also, the initial steps in elementary science curriculum revision were underway.

Identify Underlying Concepts

A first step in identifying alternative conceptions of energy is to describe the scientific concepts underlying the factual propositions identified previously. Physicist Richard Feynman has offered a widely-cited description of the scientist's understanding of energy:

> "...there is a certain quantity, which we call energy, which does not change in the manifold changes which nature undergoes. That is a most abstract idea, because it is a mathematical principle; it says that there is a numerical quantity that does not change when something happens. It is not a description or a mechanism, or anything concrete; it is just a strange fact that we can calculate some number and when we finish watching nature go through her tricks and calculate the number again, it is the same." (Feynman, cited in Approaches to teaching energy, 1987, p. 4)

Since scientists regard energy as an abstract numerical quantity, non-mathematical discussion of energy and its characteristics must perforce involve the use of metaphor. Driver and Miller (1986) report three fundamental energy-pictures suggested by participants in a workshop on study and teaching of energy:

1. degradation-dissipation: Energy changes in location and distribution. Its characteristics do not change.

2. flow-transformation: Energy is like a river, an actor with different disguises, or a person with different roles (worker, husband, father) adopted for different purposes or in different circumstances. Historically, this picture may have been the genesis of the abstract energy concept discussed earlier.

3. sources-containers: Some objects provide energy, either because it is stored in them or because it appears from them, like water from a tap. Energy is implicitly viewed as a kind of stuff and granted some degree of material character. This image may be inevitable whenever energy is quantified.

A more detailed and widely-accepted analysis of the scientific concept of energy was outlined by Duit (1981). He suggests that scientists conceive of energy in terms of five essential features: quantity, transfer, conversion of form, conservation, and degradation.

1. quantity: Physical systems and processes can be described in terms of a calculated quantity called energy. Energy is thus an abstraction. Nevertheless, it is often convenient to speak of it as a quasi-material thing, a sort of generalized fuel associated with changes in the world. Energy is associated with differences (Ogborne, 1990) and with mass, according to Einstein's description of mass-energy equivalence (Ogborne, 1986).

2. transfer: Energy can be transferred from one system or place to another.

3. conversion: The energy involved in a change is often pictured as having a specific form; for example, kinetic energy or the various types of potential energy. Although ubiquitous, this model has been challenged by Ellse (1988), who argues that it would be preferable to describe calculations of energy changes as taking various forms. Students could thus distinguish between different types of "working" (electrical working, heat working, and so on) while maintaining an unitary, abstract concept of energy itself.

4. conservation: In a closed system, the total energy remains constant, despite transfers and changes in parts of the system. It is for this reason that physicists find energy a useful quantity to calculate.

5. degradation: When a physical system changes, the energy involved may not remain available for the same process in the future. In particular, as energy is progressively transformed it becomes less capable of being harnessed to do useful work. Mathematically, the "value" of energy to cause change is described by another abstract quantity called entropy. Qualitatively, energy is said to be degraded or dissipated as it becomes less able to cause changes.

In summary, energy is a characteristic of physical systems that appears in various forms and can be transferred between parts of a system, but under appropriate conditions it is seen to be conserved and progressively degraded by physical processes. This characterization of the scientific energy concept has been adopted in much alternatives conception research.

To account for all the knowledge propositions drawn from the Alberta science curriculum, it was necessary to add an additional category to Duit's scheme: "husbanding". In it were placed curriculum statements about restraining use of energy resources on personal and societal levels. It is recognized that this sort of energy education is, at best, an application of scientific conceptions rather than a core element of them. Current public school science curricula, however, commonly go beyond strictly scientific ideas to technological implementations and applications to social issues (Alberta education, 1990). Indeed, developing a "citizen's conception" of energy has been proposed as a main goal for the study of energy in schools (Approaches to Teaching Energy, 1987; Solomon, 1986; Wellington, 1986). Thus, the addition of a "husbanding" category to Duit's scheme was considered appropriate for the purpose of classifying curriculum statements.

Validate Content Knowledge Base

The content validity of the description of scientific knowledge prepared so far was established by systematically comparing the knowledge propositions and concept statements. As previously shown in Table 2, each of the 28 knowledge propositions exemplifies at least one of the six essential features of a scientific energy concept. Similarly, each of the essential features is represented by several knowledge propositions. Thus, the propositions drawn from the Alberta science curriculum and the expanded Duit characterization of energy were taken as referring to the same area of knowledge. Instruments based on the knowledge base were presumed to have content validity.

Exploring Alternative Conceptions

Literature Search

Interview and survey items for the study needed to incorporate known alternative conceptions of energy in order to establish their existence and prevalence among Alberta students (research question 1). Therefore, an extensive review of existing studies of student understanding of energy was undertaken, in order to identify common mistaken beliefs as well as functional alternatives to the scientific conception described earlier. An extensive literature was discovered, dating back to the late 1970's. In it, questionnaire studies of students' free associations and definitions for energy conducted by Duit (1984) and extensive interview studies by Stead (1980) and Watts (undated, 1983a) suggested two major differences between alternative and scientific conceptions of energy.

First, non-scientists tend to associate energy with particular circumstances rather than viewing it as a general, abstract characteristic of physical situations. Young children, for example, commonly maintain that living creatures have energy, but non-living objects lack energy by their very nature. Second, non-scientists do not share the scientists metaphoric use of energy language and images. Of necessity, a non-mathematical scientific discussion of energy must utilize metaphoric images and language, as discussed above, but scientists recognize such usage as metaphor. Non-scientific conceptions may grant the images a greater degree of reality. Everyday consideration of energy conservation is a case in point, in which energy (rather than fossil fuel) is seen as a consumable substance. (It should be noted that these examples are intended to highlight differences in alternative conceptions of energy, not to suggest that one is more functional or "correct" in some general sense.)

Information from observational studies has been organized in several ways. Seven recurrent alternative frameworks were outlined by Watts (1983a). They were used in reviews by Brook (1986) and Brook and Driver (1984) to integrate findings to those dates.

A simpler organizational structure had been used by Solomon (1983c), who linked student examples of energy use to four everyday language "provinces of meaning," two related to living things and two related to machines. A further reduction was made by the Children's Learning in Science Project (CLISP) (Approaches to teaching energy, 1987), which noted that the word "energy" is closely associated with force, power and similar terms, and that lay usage often appears ambiguous. Nevertheless, CLISP identified three key features of a "lay meaning" of energy: (1) energy is substantive and can change into other things; (2) energy causes things to happen when it is present or active; (3) energy, like a fuel, is used up by activity, so activity stops when it is gone.

During the present study, the CLISP statements came to be considered as answers, for which three questions were eventually constructed: (1) What situations is energy associated with? (2) What is the nature of energy? (3) What happens to energy over time? The findings of previous research, as well as observations from the present study, fit well into this framework. It has been used to organize the following description of known alternative conceptions of energy, which was synthesized from primary sources and the review articles mentioned above. (Identifying labels in quotations are this author's; others are those originally used by Watts.)

1. What is energy associated with? A scientific concept associates energy with any physical situation. Alternative associations include:

1.1 living things (Solomon, 1983a; Stead, 1980) - "animate" framework;

1.2 human beings or objects considered to have human characteristics (Stead, 1980; Watts, 1983a) - human-centred framework;

1.3. movement (Brook & Driver, 1984; Solomon, 1983a; Watts, 1983a) - obvious activity framework;

1.4. the performance of useful work by technological devices (Duit, 1981; Solomon, 1983a; Watts, 1983a) - functional framework;

1.5 force or power (Approaches to teaching energy, 1987; Brook & Driver, 1984; Duit, 1981; Watts & Gilbert, 1982) - "undifferentiated" framework.

2. What is the nature of energy? A scientific conception sees energy as a convenient, abstract, calculable quantity. Alternative conceptions include:

2.1 a health/life force present when living creatures are "energetic" (Solomon, 1983a) - "vitalism" framework;

2.2 a substance-like source of activity or causal agent (Gilbert & Pope, cited in Brook, 1986; Watts, 1983a) - "substantive" framework.

3. What happens to energy over time? A scientific conception sees energy being transferred, transformed and degraded, but always conserved in closed systems.. Alternative conceptions include:

3.1 energy is possessed or stored by some objects until it is needed or used up by others (Gilbert & Pope, cited in Brook, 1986; Watts, 1983a) - depository framework;

3.2 energy circulates or is carried through a system like a fluid (Duit, 1981; Watts, 1983a) - flow transfer framework;

3.3 energy is suddenly produced from other ingredients or triggered into activity from a dormant state or possibility (Watts, 1983a) - reactive ingredient framework;

3.4 energy is released or given off as result of some other activity (Stead, 1980; Watts, 1983a) - byproduct framework.

Item Preparation

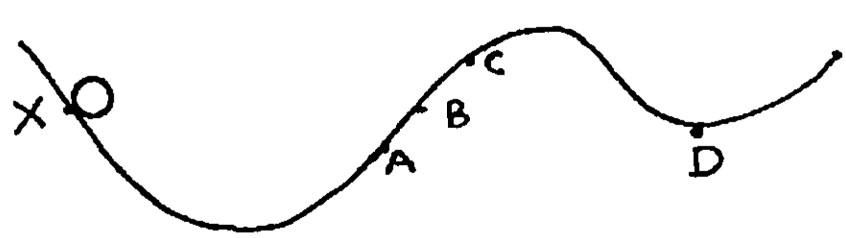
Items were developed in pairs within the framework of the content propositions identified earlier. The members of each item pair depicted different situations but were based on the same factual propositions. One item of each pair was used in the survey while the other was used during the interview. The resulting interview and survey instruments are reproduced below.

Interview Items

The cards reproduced below were presented to subjects in order, following the script (Appendix C). Items 0, 4, 8, and 10 were also represented by the apparatus pictured on the cards, which was displayed while the item was being discussed.

Interview Card 0

Ball on track



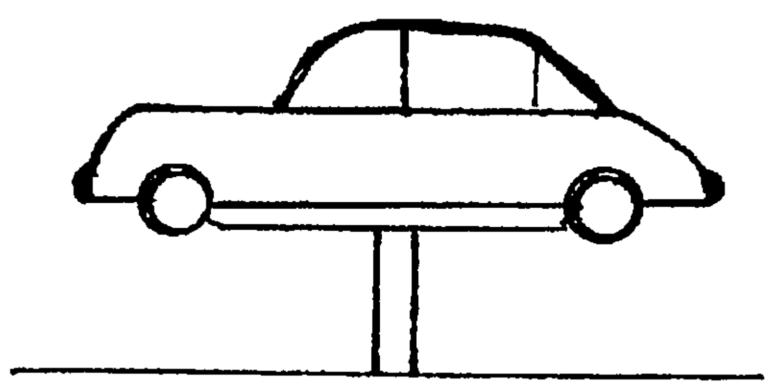
The ball is stuck to the side of the track.

Then the ball breaks loose and starts to roll down the track.

Interview Card 1
House in winter

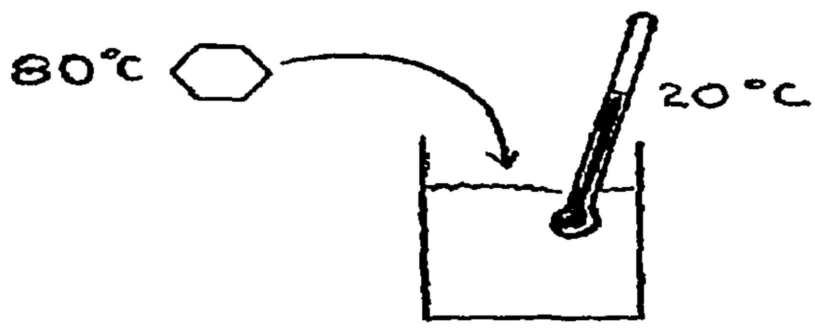
The house door has been left open on a cold winter day.

Interview Card 2
Car on hoist



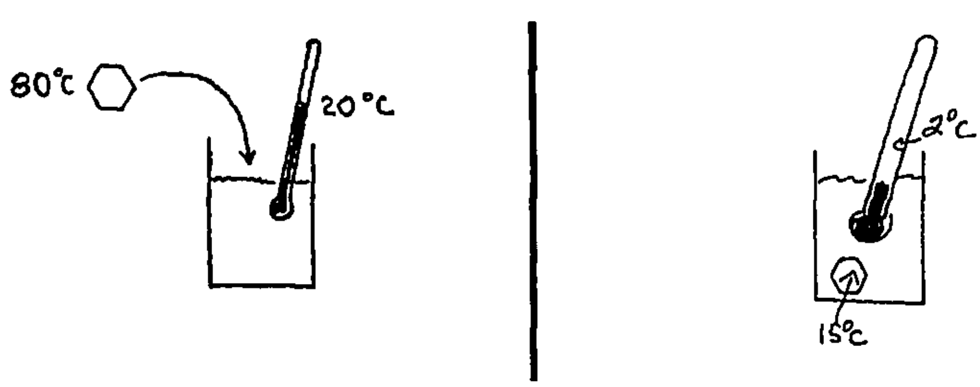
The car is not moving.

Interview Card 3a
Hot metal



A piece of hot metal is put into a beaker of cold water.

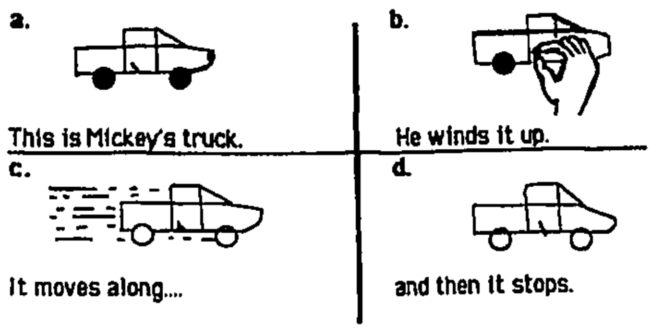
Interview Card 3b
Hot metal



After several minutes, some students observe this result.
Is this possible?

<u>Interview Card 4</u>

<u>Mickey's truck</u>

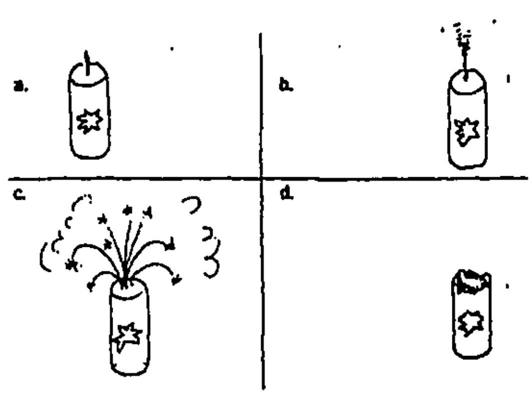


When is there an energy change?

a. from a to b
b. from b to c
c. from c to d
d. There is no energy change.

<u>Interview Card 5</u>

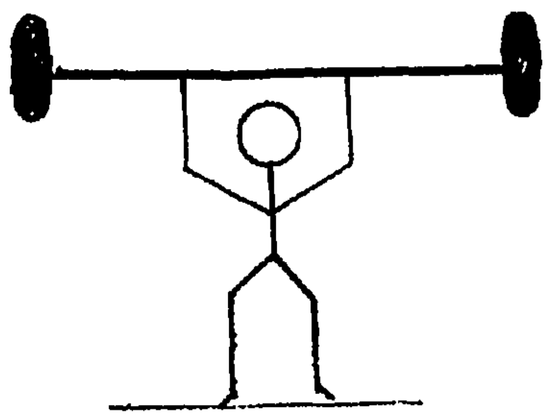
<u>Fireworks</u>



When does the firework have the most energy?

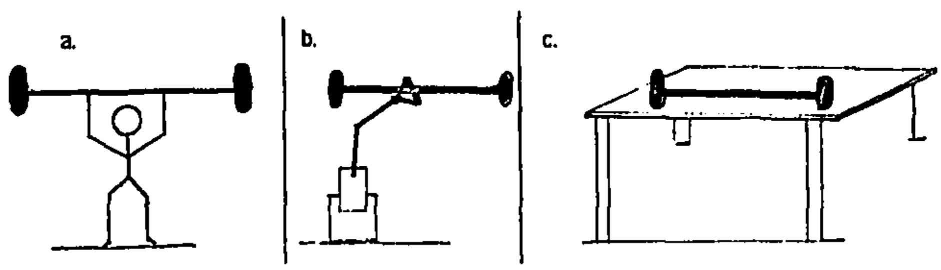
a. before it is lit
b. just as it is about to go off
c. as it goes off
d. after it has gone off
e. There is no change in energy.

Interview Card 6a
Weightlifter



The weightlifter is not moving the barbell while he holds it.

Interview Card 6b
Weightlifter



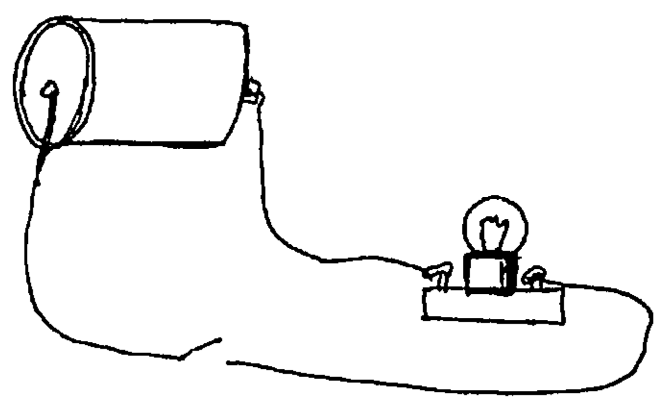
held by weightlifter | held by machine | held up by table

When does the bar have the most energy?

a. when it is held by the weightlifter
b. when it is held by the machine
c. when it is held up by the table
d. It has the same energy in each situation.

<u>Interview Item 7a</u>

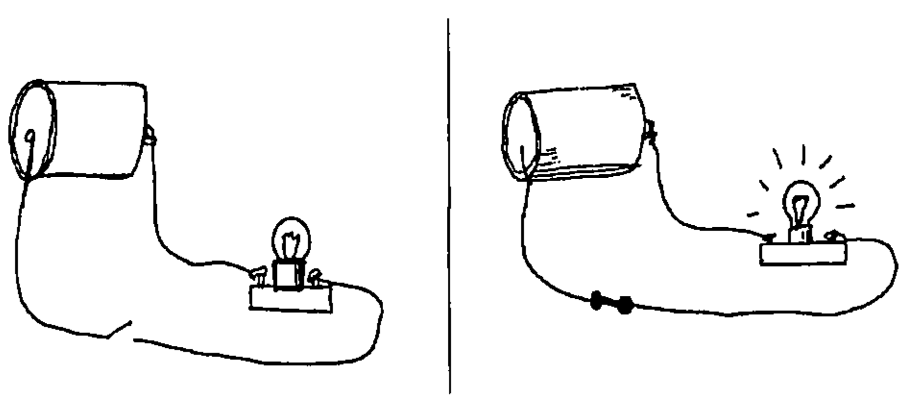
<u>Electric Light</u>



The battery is connected to the bulb, but the switch is open.
Which part of this circuit would you describe using the word **energy**?

<u>Interview Card 7b</u>

<u>Electric light</u>



Now the battery is connected to the bulb, and the switch is down.
Which part of the circuit would you describe using the word **energy**?

Interview Card 8a
Grip strengthener

The athlete is squeezing the grip strengthener.

Interview Card 8b
Grip strengthener

a.

holding tightly

b.

loosening the grip

c.

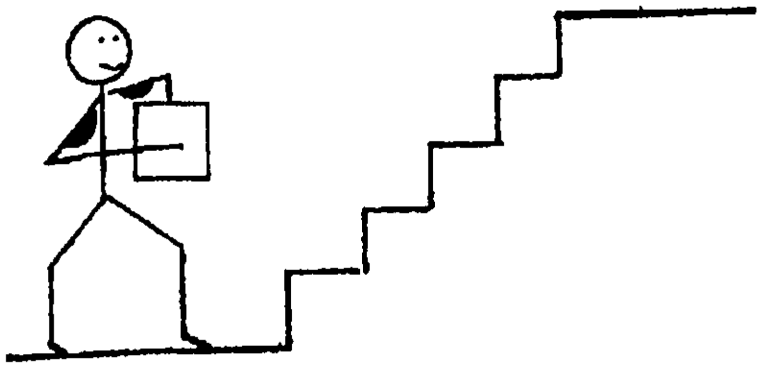
letting go completely

When is there an energy change?

a. from **a** to **b**
b. from **b** to **c**
c. from **a** to **b** and from **b** to **c**
d. There is no energy change.

Interview Card 9a

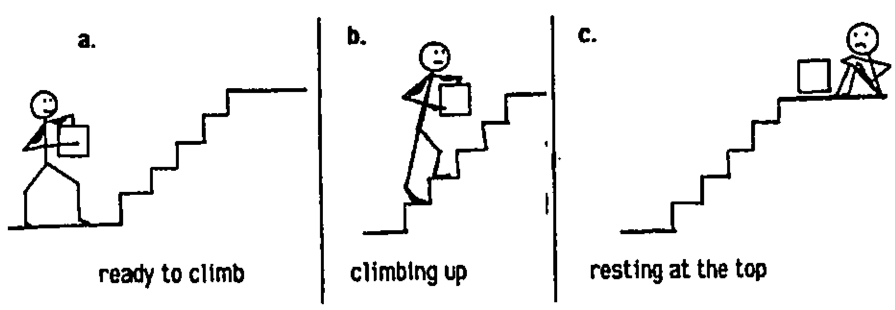
Climbing stairs



The person is standing still, ready to carry the load upstairs.

Interview Card 9b

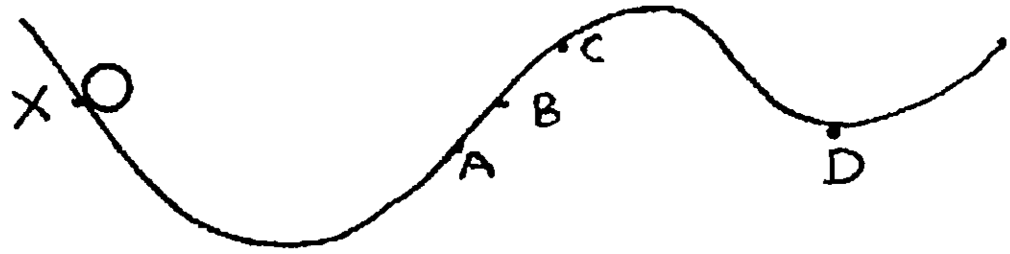
Climbing stairs



Where is there an energy change?

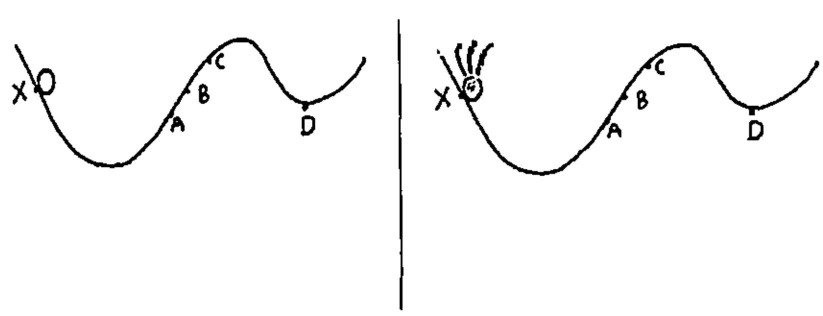
a. from a to b
b. from b to c
c. from a to b and from c to c
d. There is no energy change.

Interview Card 10a
Ball on track



The ball is stuck to th· side of the track.

Interview Card 10b
Ball on track



The ball is stuck to the side of the track. The ball breaks loose and starts to roll down the track.

How far will the ball roll?

a. to point a
b. to point b
c. to point c
d. to point d

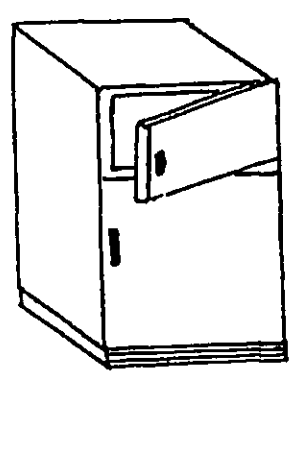
Survey Instrument

This survey is part of a research project about the way Canadian students describe and think about various situations. I am interested in the **different** ideas that people have, so there are no right or wrong answers. Try to explain your ideas clearly, so I will be able to understand how you are thinking. You can use examples or diagrams in your explanations if you want.

PLEASE DO NOT MARK THE QUESTION BOOKLET. On the answer sheet, circle the letter of your answer and write your explanation in the space provided. In a few days, after I have read your survey, I may ask you to clarify some answers. After I am sure that I understand your thinking, your name will be removed from the answers before they are analyzed and reported. Your answers will **not** affect your grades in this course!

Thanks for your help with this research.

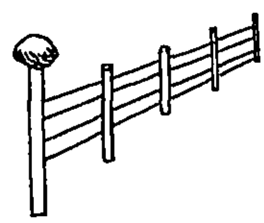
Survey Item 1
Refrigerator



The freezer door on the refrigerator has come open.
In a few sentences, describe as much as you can about what is happening in this situation.

Survey Item 2

Rock and fencepost



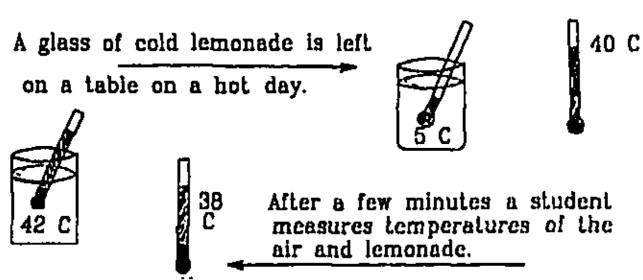
The rock is balanced on top of the fencepost.

Which statement below gives the best description of **energy** in this situation?

a. There is no energy here.
b. The rock has more energy on top of the post than if it were lying on the ground.
c. The rock and post (and the earth below them) have more energy than if the rock were lying on the ground.
d. The energy of the post is being used up holding the rock.
e. The energy of the rock and post (and the earth below them) is being used up holding the rock.

Survey Item 3

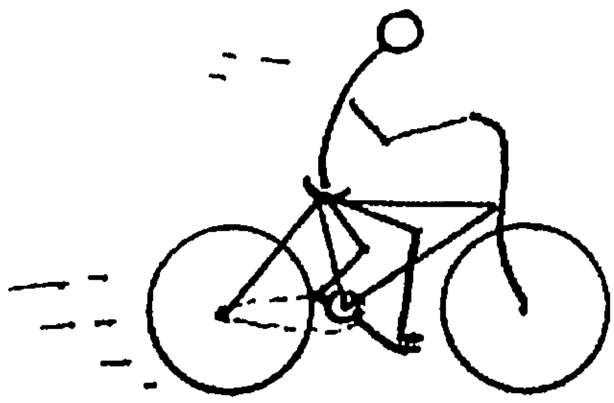
Lemonade



The student must decide whether the measurement is reasonable. What is most important in making that decision?

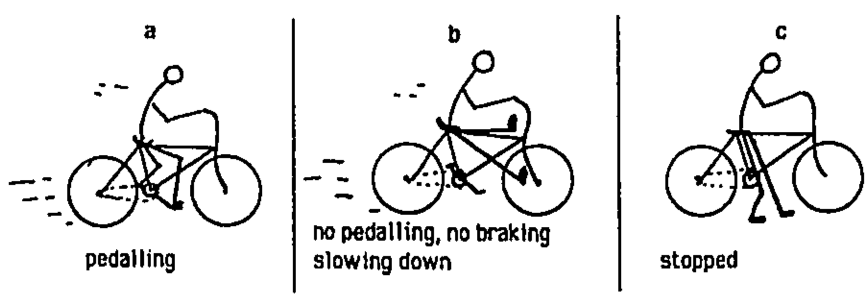
a. The lemonade would not warm up so much in just a short time.
b. The air near the glass would cool down more as the lemonade warms up.
c. The two temperatures would end up equal.
d. The lemonade would never get hotter than the air around it.
e. The measurement seems reasonable, but it would be sensible to repeat it just to make sure.

Survey Item 4a
Bicycle



The bike is being pedalled along the street.
Think about **energy** in this situation.

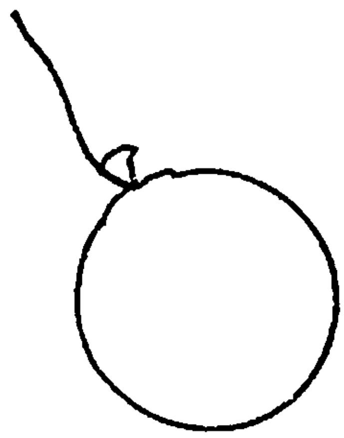
Survey Item 4b
Bicycle



The rider stops pedalling. The bike coasts along, slows down, and stops.
Where are there energy changes?

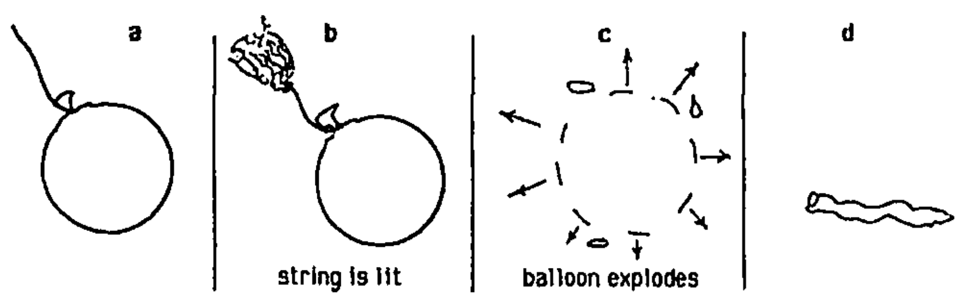
a. from **a** to **b**
b. from **b** to **c**
c. from **a** to **b** and from **b** to **c**
d. There are no energy changes.

Survey Item 5a
Balloon



The balloon has been blown up and tied with a string.
Think about **energy** here.

Survey Item 5b
Balloon

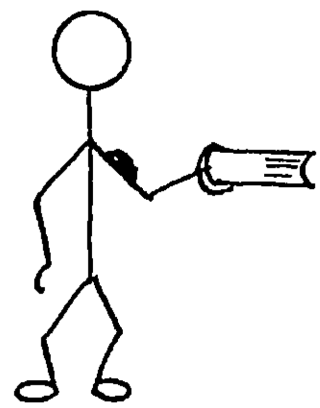


The string burns and the balloon explodes.
When does the balloon have the **most** energy?

a. before the string is lit
b. after the string is lit
c. as it explodes
d. after the explosion
e. The energy stays the same.

Survey Item 6a

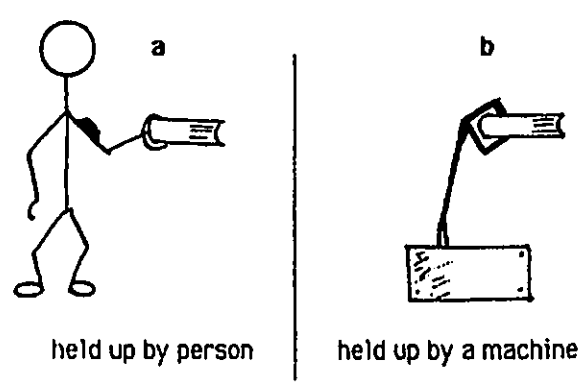
Holding a book.



The person has lifted the book and is holding it still.
Think about **energy** here.

Survey Item 6b

Holding a book

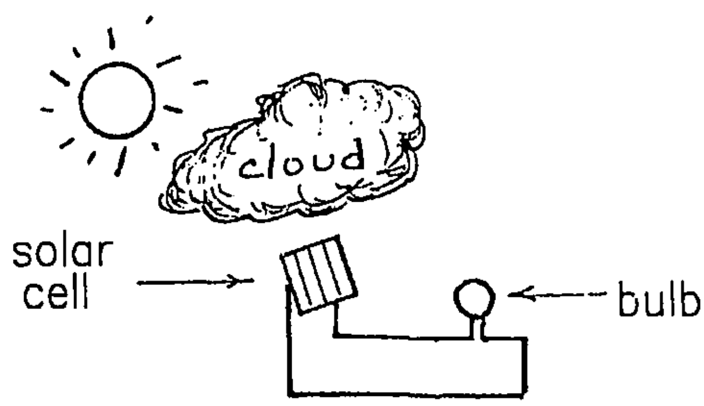


In which situation is there the biggest energy change?

a. when the book is lifted up by the person
b. when the book is lifted up by the machine
c. The energy change is the same for both ways of lifting.
d. There is no energy change when the book is lifted.

Survey Item 7a

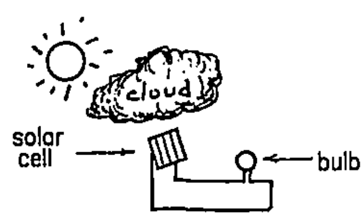
Solar cell

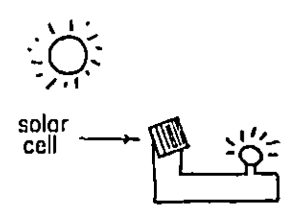


The solar cell is connected to a lightbulb, but a cloud shades it from the sunlight.
Think about **energy** in this situation.

Survey Item 7b

Solar cell



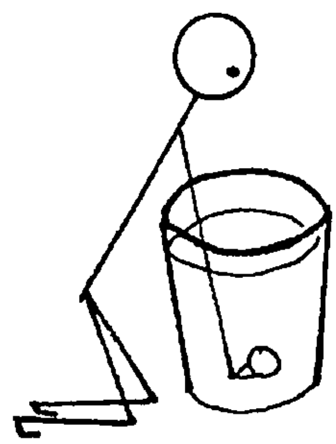


Now the cloud has moved and the lightbulb lights. Which description best fits your idea of **energy** in this situation?

a. Sunlight releases the energy of the solar cell so the bulb lights up.
b. Electricity produced by the solar cell makes the bulb release its energy and light up.
c. The electric current in the circuit gets "charged up" with energy in the solar cell and carries it to the bulb, which lights up.
d. Light energy from the sun is changed into electrical energy by the solar cell and then back into light energy by the bulb.
e. Electrical currents from the solar cell go through both wires, meet in the bulb, and react to produce light energy.

Survey Item 8a

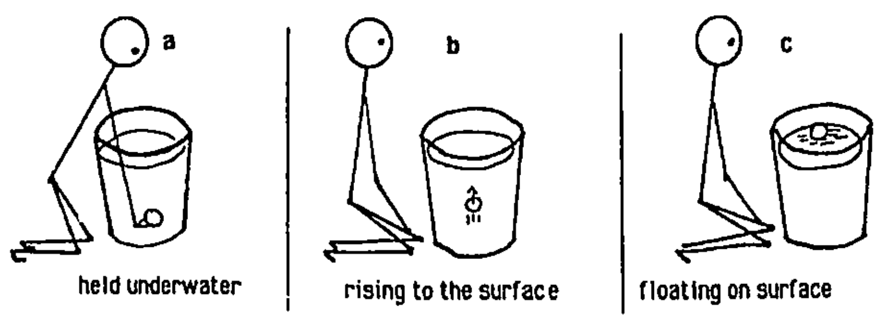
Ping-pong ball



The person is holding the ping-pong ball under water.
Think about **energy** in this situation.

Survey Item 8b

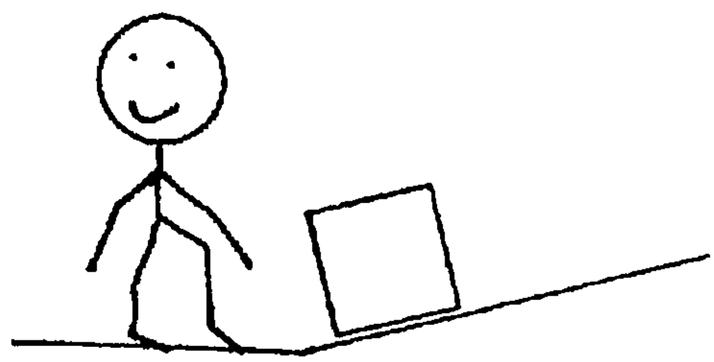
Ping-pong ball



The person lets go and the ping-pong ball pops to the surface. Which part of this situation could be described using your idea of **energy**?

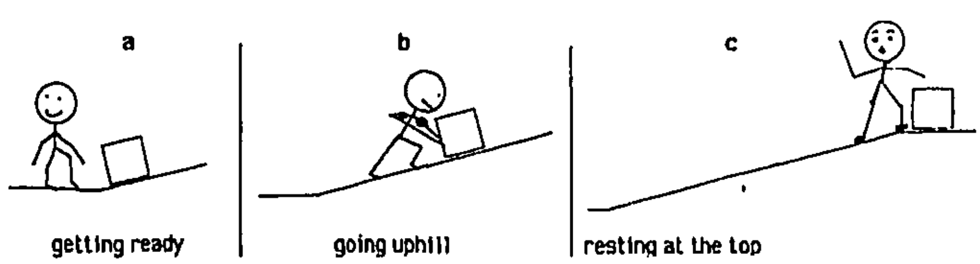
a. Only part **a** where the person is forcing the ball to stay underwater.
b. Only part **b** where something is moving.
c. Only part **c** where the ball is at a higher level and the person is (a little bit) tired.
d. My idea of energy applies to more than one part.
e. There is no energy here at all.

Survey Item 9a
Load and hill



The person is standing still, ready to push the box up the hill.
Think about **energy** in this situation.

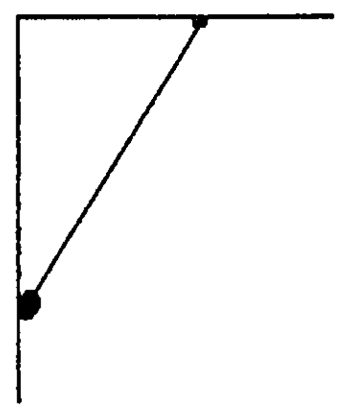
Survey Item 9b
Load and hill



The person pushes the box up the hill and then sits down to rest. Which description best fits your idea of the **person's energy** as the box is pushed up the hill?

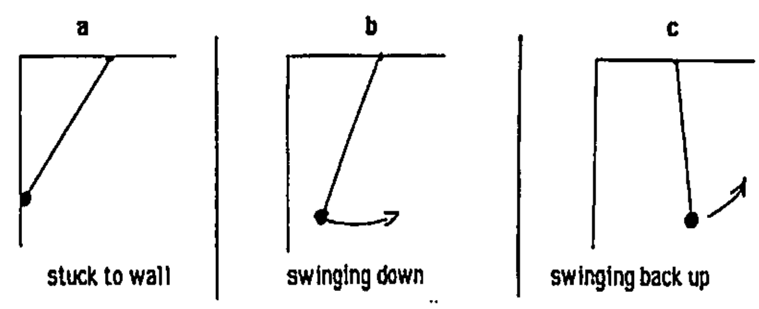
a. Energy is being produced in the person's body so the work can be done.
b. Energy is being transferred from the person into the box.
c. Energy is being shared between the box, the surroundings, and the person's body.
d. Energy is being used up pushing the box.
e. My idea of the person's energy is different from all of these.

Survey Item 10a
Pendulum



The pendulum is glued to the wall.
Think about **energy** here.

Survey Card 10b
Pendulum



The glue breaks, and the pendulum swings down and then up again. If we measured the pendulum's energy, our answer would

a. be highest in **a** and go steadily down as the pendulum swings
b. be lowest in **a** and go up as the pendulum gathers energy to swing
c. be high in **a**, go down as the pendulum swings lower, and then go back up in **c**
d. be low in **a**, go up as the pendulum swings faster, and then go back down in **c**
e. stay the same in **a**, **b**, and **c**

Item Content

Table 4 (below) summarizes the content basis for each pair of items in terms of the propositions extracted from the Alberta science curriculum and described earlier. Because all items portrayed situations which can be described and explained using knowledge included in Alberta science programs, the items are considered to have content validity.

The interviews and survey were designed as a selective, rather than exhaustive, probe of knowledge defined by the content propositions. No items were directly related to propositions 11 (sound as a form of energy), 15 and 16 (the sun as source of earth's heat and chemical energy), 23 (kinetic energy in collisions) and 27 and 28 (energy use and environmental change, and alternative energy sources). These omissions were made primarily to reduce the number of items, to restrict them to topics which all subjects would likely have considered during recent school courses, or to meet the additional item design criteria discussed below.

It was previously established that a scientific conception of energy, as described by Duit (1981), underlies the content propositions. Thus, items based on those propositions allowed students to display a scientific conception of energy. In addition, either the situation or the multiple choice responses for each item embodied alternative conceptions of energy described in the literature (Table 5, below).

Table 4. Content Basis for Items

Proposition	Interview/Survey Items									
	1	2	3	4	5	6	7	8	9	10/0
1				x	x	x		x	x	x
2			x	x	x		x	x	x	x
3						x		x	x	
4		x	x	x			x		x	x
5	x		x							
6	x		x							
7		x		x	x	x	x	x	x	x
8				x	x	x	x	x	x	x
9		x		x	x	x		x	x	x
10							x			
11										
12							x			
13						x	x	x		
14						x		x	x	
15										
16										
17				x		x		x	x	
18	x		x							
19					x					
20	x		x							
21	x		x							
22	x		x							
23										
24		x	x	x	x	x	x	x	x	x
25			x	x	x	x	x	x	x	x
26	x									
27										
28										

Table 5. Conceptions Illustrated by Item Responses

Conception	Item																	
	4a	4b	5c	6a	7a	7b	7c	7e	8a	8b	9a	9b	9c	9d	10 a	10 b	10 c	10 d
Animate	x			x					x									
Motion		x	x							x						x		x
Useful task											x							
Depository														x	x		x	
Flow/ Transfer							x	x				x	x					
Ingredient/ Byproduct					x	x												

All items contained an open-ended opportunity to express unforseen interpretations. Items were thus designed to elicit a wide range of conceptions, from the orthodox scientific to the completely idiosyncratic. Development of items was also guided by several additional criteria.

1. familiarity: Situations which are familiar in students out of school experience were selected as being most likely to evoke "commonsense" description and explanation. Totally novel situations, and those familiar only through school science, were avoided. It was hoped that this would reduce subjects' attempts to plead ignorance or to please the interviewer by providing the sort of answers usually expected in a school context.

2. variety: Situations were chosen to reflect all underlying concepts and alternative orientations identified in the previous phase of the study.

3. availability of parallel items: Items for the interview and written survey were developed in pairs intended to present similar underlying concepts in superficially different situations. Comparison of subjects' responses to parallel items could thus be used to provide an indication of the instrument's construct validity.

4. previous use: Interview-about-instance situations and interview questions found useful in previously reported studies were used as a basis for all items except 1 and 7. Sources are listed in Chapter 4, "Findings".

5. visual character: To permit the widest possible latitude in description and explanation, situations were presented in sketch form, with minimal captions and directions. Three items were represented with concrete objects as well as diagrams: a marble rolling on a curved plastic ruler was used to model item 1; a wind-up model truck demonstrated item 4; and an actual grip strengthener was displayed during the presentation of item 8.

The items were ordered from free responses toward more specific cues and forced choices. This was done in order to test previous findings that students seldom utilize the term "energy" in explanations unless directly cued (Brook & Driver, 1984; Duit, 1990). Items 0 and 1 therefore contained no reference to energy, although the situations invite use of the concept. Item 2 specifically proposed energy as a possible descriptor. Item 3 again presented a situation in general terms, without reference to energy. All remaining questions included specific, energy-related alternative answers, as well as opportunity for free responses.

The use of sequences of pictures was intended to evoke comparisons and discussion of the dynamics of energy change. Multiple-choice responses were also intended to focus discussion and provide a degree of parallelism between the interview and written survey. Finally, item 10 repeated item 0, providing the subject with a chance to amplify or modify previous responses once an energy-related mind-set had been established.

Items chosen for use in the survey included a request for written justification of the chosen response. In addition, responses to selected items were worded to reflect the same conceptual orientation, so that the consistency with which students expressed particular orientations could be ascertained (Chapter 4, "Findings: Consistency of Responses" and Tables 19 and 20). It was anticipated that survey items would need to be augmented or revised in the light of interview results, but this was not necessary. However, a minor clarification of wording for item 6 was suggested by the instructor of the physics 20 class and incorporated into the surveys given to all other classes..

Interview and Survey Administration

Population and Sample

Subjects for the study were a stratified sample of students at Crescent Heights High School in Medicine Hat, Alberta. One of two public high schools in a city of about 45 000 people, Crescent Heights has a student population of about 1100, largely drawn from middle class families of European origin. The school offers a comprehensive program of studies with an academic focus. Senior students who wish vocational programs attend the other public high school in the city.

Thirty nine students in two grade 9 classes (roughly 20% of the grade 9 population of the school) participated in the study before beginning their unit on energy. The students were heterogeneously grouped, and although their class rosters had been rearranged each year, all students had received similar science instruction since grade 7.

One grade 11 class in each of general science, biology, and physics participated in the study. These 45 high school students represented about 30% of the school's grade 11 population. Within each high school class, students tend to show a greater homogeneity of interests and abilities than in grade 9. This arises naturally as students choose whether to study one or several of the specific disciplines or to remain in general science. At the time of the study, the general science courses did not qualify students for post-secondary study and thus tended to be chosen by those who were less academically interested or capable.

The largest proportion of students attempting to qualify for post-secondary study choose biology, either through interest or to satisfy graduation requirements in what is perceived as the least demanding way. A much smaller proportion of students choose physics, which requires some mathematical competence and is seen by many students as the most difficult science.

Chemistry students were not included in the study because the majority of them also take physics or biology. Grade 12 classes were not surveyed because no general science class is available at that level.

Permission to conduct student interviews and written surveys was obtained from Medicine Hat School District #76, the school principal, and the teachers involved. Parents of participating students were notified of the study and their permission for student participation in interviews was sought (Appendix A). Approval of the Faculty of Education Human Subject Research Committee of the University of Lethbridge was obtained and the committee's research guidelines were followed.

From each class two interview subjects, one male and one female, were randomly selected from students having parental permission to participate. Table 6 (page 92) gives relevant demographic information for the interview subjects. Because some permission slips were not returned, interview subjects were not a truly random sample of students in the selected grade 9 and 11 classes. However, since the purpose of the interviews was to explore a few individual's ideas in depth, this sampling procedure was considered adequately representative.

The survey instrument was completed by all students in the participating classes, including the interview subjects, except for those absent on the chosen day. Table 11 (page 111) gives a breakdown of survey subjects by grade level and course of study.

Research Procedures

Interviews. Eight interviews were conducted during class time over a period of three days. The interviewer and subject were able to work undisturbed in preparation rooms adjacent to classrooms. Each 20 to 30 minute interview was tape recorded, with the subject's permission, for later transcription and analysis.

A semi-structured format was employed using a predefined script. Subjects were asked to describe and analyze pictorial representations or models of ten situations. The interview script is reproduced as Appendix B. In general, the discussion was crafted to move from general description and free responses toward more specific cues and forced choices. It was thus hoped to provide opportunities both for expression of novel ideas and for the validation of specific previous findings.

Survey. Eighty four survey instruments were completed during a 1 week period under the supervision of the co-operating teachers, who determined the time of administration. No time limit was imposed upon the students as they worked through the survey, but teachers reported that most students required 30 to 40 minutes of apparently diligent effort.

Analysis

Interviews

Transcripts were examined on two levels. First, student generated statements about energy were matched with the knowledge base of propositions, concepts, and common misconceptions identified earlier. The resulting variety of statements related to each item was given a preliminary examination to establish the likelihood that existing alternative conceptions research on energy might indeed be applicable to Alberta students and thus confirm the wisdom of proceeding with the study.

Student statements were then reexamined as possible indicators of alternative conceptual orientations. Statements which did not fit orientations already described in the literature, were described according to their underlying theme and structure.

Since the purpose of the interviews was essentially to confirm and flesh out previous findings, their number was kept small enough to be managed by informal means. Formalized systems of transcript annotation and proposition or thematic sorting were not used.

<u>Survey</u>

For each question, survey papers were sorted according to which multiple-choice response was chosen. Papers were then grouped according to the justification proposed by the student. These clusters of responses were then described, illustrated with quotations, and if possible linked to common alternative conceptions.

One group chi-square analysis was used to confirm that question responses were unlikely to have occurred by chance. Patterns of multiple choice responses in different classes were compared using contingency tables and multiple group chi-square analysis. However, the number of responses was only marginally adequate for such analysis, and the questions were not designed primarily for this purpose. Thus, the statistics must be regarded as suggestive rather than definitive.

The strength of individual subjects' adherence to particular conceptual orientations was then investigated (research question 5). Responses to selected pairs or triples of alternatives which expressed the same orientation on different items were tallied. The actual number of subjects who expressed the same conceptual orientation on more than one question was compared to the theoretical probability that independent choices would produce similarly consistent responses.

Responses from 7 of the 8 subjects who participated in both the interview and the survey were used to investigate the concurrent validity of the survey. The interview response was taken as criterion. Because the survey and interview schedule were not identical, no statistical measure of test-retest reliability was strictly applicable. The number of subjects and sufficiently parallel items was, in any case, too small to justify statistical inference. However, the number of consistent and inconsistent responses to similar questions was tallied and considered to be an indication of concurrent validity.

Summary

A variety of research methods developed to probe children's alternative conceptions were reviewed and, within the limitations of small-scale, exploratory research, drawn upon in the initial study design. Following procedures outline by Treagust (1988) and Gilbert, Watts & Osborne (1985), an interview protocol and a survey instrument were created to investigate children's ideas about energy. Specific features of the study were designed to facilitate investigation of each of five research questions.

1. Would alternative conceptual orientations reported in the literature also be evident in interviews and written surveys of Alberta students? The study utilized question situations drawn from previous studies, as well as original items. Student responses could thus be directly compared with those found in the original studies. Original questions and multiple choice responses were written to reflect alternative conceptions described in previous research.

2. Would subjects show a similar pattern of responses to interviews and written surveys? Interview subjects also wrote the survey, so their responses in the two situations could be compared. Although the situations portrayed in the survey differed from those considered during the interview, corresponding items on the two instruments were developed in parallel, were similar in key features, and exemplified similar conceptions. The inclusion of an open-response justification for each survey response permitted elaboration of answers and provided an opportunity for interpretive analysis of an otherwise objective instrument.

3. Would there be noticeable differences in responses between grade 9 subjects, who have not received a formal introduction to energy at secondary school level, and grade 11 subjects, who were introduced to the topic two years previously? The sample included subjects at both grade levels. Both multiple-choice and open responses could be tallied by class and compared. Patterns of multiple choice responses from different classes could be analyzed using multiple-group chi-square analysis, although the limited size of the sample meant that results could not be treated as definitive.

4. Would the proportion of students utilizing a scientific orientation vary between classes? Essential features of a scientific conception of energy were established and opportunities to express them were incorporated into the interview and survey. The number of student responses which reflected aspects of a scientific orientation could be tallied by class and compared.

5. Would students consistently utilize a given conceptual orientation? Multiple choice responses exemplifying each of several particular conceptions were included in more than one survey question. The number of subjects whose responses consistently expressed a particular orientation could thus be tallied and compared to chance expectations. Additionally, interview transcripts could be considered at length, in order to uncover underlying consistencies of orientation in an interpretive fashion.

Chapter 4

Findings

Introduction

The eight exploratory interviews provided ample evidence of many previously described alternative conceptions of energy. All of the questions proved successful in eliciting divergent responses, variations of interpretation, and novel, student-generated examples and phraseology. Summaries of recurrent and unusual responses and illustrative quotations documenting findings related to the research questions are presented below.

Survey items were administered in their original form to the physics 20 students. A revised wording of item 6 was suggested by the instructor, adopted, and used in the surveys completed by the remaining 73 subjects. Comments on the anticipated and actual responses and written justifications for each of the 10 questions are presented below, along with multiple-choice response patterns by class and illustrative quotations. Additional discussion of each alternative response, supported by further quotations, is presented in Appendix C.

Interview Results

Overview

Demographic information about the eight interview subjects is summarized in Table 6, below.

Table 6. Interview Subjects

Subject	Class	Sex	Age	Science Achievement *	Interview Date
1.	Physics 20	F	17	A	91-05-08 am
2.	Physics 20	M	17	B	91-05-09 am
3.	Biology 20	F	17	C	91-05-10 am
4.	Biology 20	M	16	A	91-05-10 am
5.	Science 24	F	17	B	91-05-09 pm
6.	Science 24	M	17	B	91-05-09 pm
7.	Science 9	M	16	C	91-05-10 am
8.	Science 9	F	15	A	91-05-10 am

Throughout the interview process, initial reservations about the wisdom of working with subjects who had been, and might again be students of the author proved unfounded. There was no evidence of any felt need for caution or protective reticence. Rather, subjects were relaxed and ventured far beyond obedient co-operation. They worked hard to find helpful examples, provide detailed descriptions and generally establish shared meanings. Subjects appeared to enjoy having the lengthy, undivided attention of a listener and the opportunity to explore their own ideas in unusual depth. The resulting conversation was focussed and relevant, but also unexpectedly genial.

Several aspects of the conversations stood out by virtue of being frequent, unexpected or of unsuspected importance. They are summarized below and discussed later in the context of the particular interview items. Quotations are coded according to the system outlined in Table 7.

Table 7. Quotation Coding

Example

(What do think?) Well ... it [the energy] has xx // just disappeared
2: I4 3 (024)

2:	sequential citation number
I/S:	interview or survey
4:	item number
3:	subject number
(024)	transcript segment
( )	interviewer's speech
...	pause
[ ]	explanation added during transcription
xx	undecipherable
//	omitted material - judged irrelevant during transcription

1. Subjects' ideas were not always stable, but neither were they whimsical or chaotic. Instead, there was a sense of trying to describe the same situation from various perspectives, which occasionally led to contradictions as one account was replaced by an apparently more suitable one.

> (When would you say it had the most energy?) When it was up in the air. When it was flying. (Explain why.) Because to get up in the air so quick and so fast you need lots of energy, and so c has to be where all the energy comes from. Well, the most part of the energy // Like, I don't know what makes it go off, like ... probably the flame makes it go off, so ... as soon as the flame gets down, then it all goes up in the air. So, it's both. Like there's energy from there [the burning wick] that makes it go up, so ... it's both of them. 14: I5 5 (134-139)

> (Does the bar have energy?) No // He's holding the bar up. But he's not moving it. So, if he was moving it then ... I don't know ... (But he's not. He's just holding it still.) OK. Well, then, I think he has all the energy. He has to hold the bar up, so he's got the energy. 15: I6 5 (150-155)

2. The term "energy" was seldom used spontaneously in descriptions or explanations. (items 0, 1 and 10).

3. Subjects had difficulty constructing accounts of energy flow through open systems, especially those which included living creatures. Steps involving energy degradation into evenly distributed heat energy were seldom included.

> Does it [energy] have anything to do with the hoist, or is it just the car? // Well, if it's just sitting still then ... there'll be no energy, well ... it has to have energy to keep the thing up, the car up. I don't know if that's energy or whatever, but ...
> 6: I2 5 (055-056)

> (What's happening with the energy as it's moving along, then?) Well, it's being used up, probably, from the wind and the ... friction, I guess // I just see it ... unwinding and the wheels are using that [energy] to make it go, I guess. (What happens as it's used up?) It just ... is, probably, no longer and it stops. It just ... I don't know ...
> 11: I4 3 (076-081)

4. The process of establishing temperature equilibrium in a familiar physical system was surprisingly poorly described and was seldom related to energy flows in the system. Hot and cold objects were not considered in relation to their surroundings. Fluctuations above and below initial temperatures appeared to be as plausible as progressive movement towards equilibrium.

> (Would they [the final temperatures] still be different, or would they be the same?) I think they'd be a little bit different. The metal could be a little bit hotter still // 'cause the water was kind of colder and I don't think it's going to drop that far down. Like, it's not going to release all of its heat. 9: I3 8 (079-082)

> (What do you think it would be like in another few minutes?) Uh, the temperature of the thermometer would have dropped a couple of degrees and the metal would have dropped, too // (What would ... set the limit?) Probably zero // (Why do you think that would be a ... sort of limit?) 'Cause zero is when the, is the starting of the freezing point and the melting point ... of ice and water. 10: I3 7 (059-066)

5. Subjects expressed a surprising variety of relationships between heat and energy, considering the extensive study of heat they had all made in grade 9.

> Well, energy ... is like heat. It's like friction. When you move something very fast, it would warm up. If not, if you move it very slow, it would probably get cooler.
> 7: I2 7 (036)

> The metal ... it could be attracting heat, and the heat's making energy inside of it // It's just the amount of heat it attracts that's creating the energy in it // 16: I6 8 (124-126)

6. The term "potential energy" was sometimes used to signify an unfilled capacity, rather than a particular form of energy. "Potential" energy thus contrasts with "actual" energy (which subjects often termed "kinetic"). In this usage, accounts of conversion from potential to kinetic energy, although superficially orthodox, refer to more than a change between two equally "real" guises. Instead, they have a strong sense of the sudden appearance or actualization of a previous possibility.

> It [has] potential energy. And once it rolls down it would go into kinetic and then that will turn into heat energy. (In your mind, what do you mean by potential energy?) It has the ability to do work ... to release heat ... if it is released. (Has it got that ability right now // as I'm holding it?) No. (So when I release it, what happens?) Then it has energy // when it's released it's got kinetic energy // It changes into kinetic.
> 1: I0 2 (012-028)

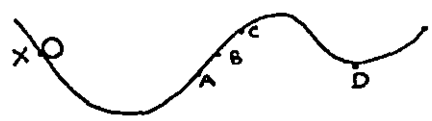
7. In static situations, such as a car on a hoist, energy was sometimes considered as necessarily present to prevent motion. This extends the notion of energy as a fuel which causes motion.

> (Is there any energy there [initially]?) While it's sitting there? ... hm ... Probably just to keep it there. There's got to be, if that's a slope and this [marble] is sitting there.
> 2: I0 3 (178-179)

Detailed Discussion of Responses to Interview Items

Each interview item is reproduced below and its intent is summarized. A brief description of an appropriate scientific response is given, followed by a discussion of the main features of student responses.

Item 0. Ball on track



The ball is stuck to the side of the track.
Then the ball breaks loose and starts to roll down the track
(item 10 only: How far will the ball roll?

a. to point a
b, to point b
c. to point c
d. to point d

source: original

Figure 1

The intent of the question was to determine if subjects would spontaneously use any conception of energy when describing a physical system. In scientific terms, an appropriate description would involve energy transformations, conservation, and degradation due to friction.

When initially asked to describe the system, 3 of 8 subjects, including both physics students, spontaneously mentioned energy. At the end of the interview, when specifically asked to describe the same situation in terms of energy, 6 subjects were able to comply. (The remaining 2 subjects did not consider item 10, as their interviews were terminated so they could proceed to other classes.) That is, although subjects were generally capable of describing the situation in terms of energy, fewer than half did so spontaneously. Among these students, energy was not a favoured descriptive stance. By contrast, as indicated earlier, physical scientists regard energy as a powerful and pervasively useful descriptive tool.

Two subjects (1 and 2) proposed superficially scientific descriptions involving energy transformation, degradation and conservation. However, questions about the initial energy of the marble, when it was glued high on the side of the track, evoked a variety of alternative conceptions.

> It [has] potential energy. And once it rolls down it would go into kinetic and then that will turn into heat energy. (In your mind, what do you mean by potential energy?) It has the ability to do work ... to release heat ... if it is released. (Has it got that ability right now // as I'm holding it?) No. (So when I release it, what happens?) Then it has energy // when it's released it's got kinetic energy // It changes into kinetic.
> 1: IO 2 (012-028)

Here, "potential" appears to have the sense of "possible". The marble has an unfilled capacity for "real" (kinetic) energy, which only materializes when the marble is released.

Some subjects claimed that energy was necessary to cause the ball's motion down the slope. Others proposed that it was necessary to prevent such motion.

> (Is there any energy there [initially]?) While it's sitting there? ... hm ... Probably just to keep it there. There's got to be, if that's a slope and this [marble] is sitting there.
> 2: IO 3 (178-179)

However, for one subject the absence of both motion or animate objects removed the possibility of energy.

> (Here's a ball stuck to the track. Is there any energy there?) It's just stuck there, like, nobody's holding it? // Uh, no. 3: IO 7 (230-232)

Item 1: Winter house with open door

The house door has been left open on a cold winter day.
source: original

Figure 2

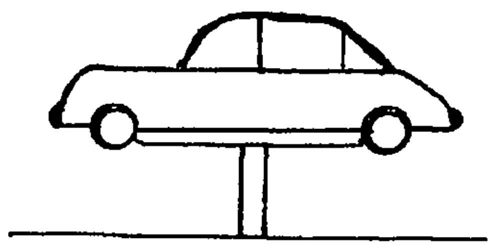
The familiar situation was intended to elicit everyday notions of husbanding energy. Appropriate scientific descriptions could be made generally, in terms of energy transfer, or specifically in terms of heat (energy) loss or transfer.

No subject spontaneously described the situation in terms of energy. All responses were in terms of moving air, resulting in a cooling of the house. Only one subject (2) ventured beyond description of observables to any sort of theoretical account. To him, heat apparently consisted of two particular kinds of atoms, hot and cold, whose proportion determines the temperature of a substance.

> There's a mixture of heat. The atoms and stuff are bouncing around and stuff. It's getting colder in the house // (Explain that a bit.) Well, as the hot and cold air come together and the atoms or whatever start bouncing around and mixing up ... they kind of dilute the hot air from inside. 4: 11 2 (048-052)

One subject (3) mentioned the inefficiency of trying to heat a house with an open door. However, as she specifically rejected description of the situation in terms of energy, her comment cannot be taken as indicating a husbanding orientation towards a well-differentiated concept of energy.

Item 2: Car on hoist



The car is not moving.

source: Stead (1980)

Figure 3

The item portrays no motion or animate objects, so it was expected that subjects holding these orientations would deny the presence of energy. An appropriate scientific description would mention the gravitational potential energy associated with the elevated car. The mechanism of the hoist, although not shown, might be described as converting chemical or electrical energy into heat if it is thought to continue running while the car is elevated.

One subject (3) strongly linked energy with motion.

> (Tell me about energy as you think of it in this situation.) Um ... (laugh) I don't think there is any energy if it's not moving. If it's not running, if it's just sitting there.
> 5: 12 3 (025-026)

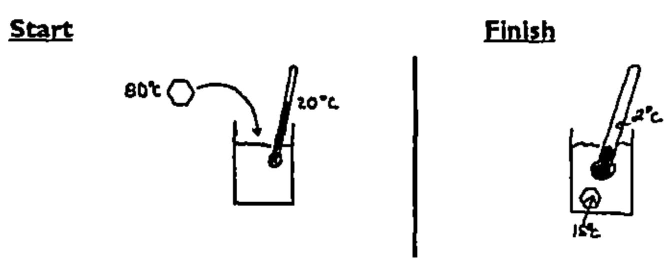
To subject (5), the lack of energy implied by a motionless car conflicted with the apparent need for some energetic agent to keep the car raised.

> Does it [energy] have anything to do with the hoist, or is it just the car? // Well, if it's just sitting still then ... there'll be no energy, well ... it has to have energy to keep the thing up, the car up. I don't know if that's energy or whatever, but ...
> 6: I2 5 (055-056)

An undifferentiated orientation was also evident, conflating energy, heat, friction and motion.

> Well, energy ... is like heat. It's like friction. When you move something very fast, it would warm up. If not, if you move it very slow, it would probably get cooler.
> 7: I2 7 (036)

Item 3. Hot metal in cool water



A piece of hot metal is put into a beaker of cold water.
After several minutes, some students observe this result.
Is this possible?

source: Duit (1990) (modified)

Figure 4

A scientific analysis would apply the notion of transfer of energy (specifically, heat energy) to conclude that the situation is not possible. The metal and the water could not both lose heat energy and get colder. The analysis is consistent with a substantive, flow-transfer image of energy. It was expected that undifferentiated views which confuse heat and energy might also surface.

Faced with a specific request to describe the situation in terms of energy, two subjects (5 and 7) found no indication of energy in the situation. Two more (3 and 6) were unsure if heat was a type of energy. Others spoke of energy (or heat energy), primarily in a depository, substantive fashion.

> The energy amount, the energy in this water is less than what's in that rock, so when the rock is there (in the water) the heat energy is lost to the water, until both equal and there's no more to give and no more ... to take // (How does that work?) Well, by touch ... transformation, like ... When this [metal] enters into the water it'll give off the energy, like from the outside, and then ... this [water] will be taking in // the water will keep taking or this [metal] will keep giving off energy until it's completely ... like, after a little period of time it will, they will balance. 8: I3 4 (O63-067)

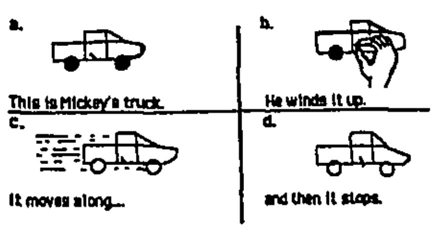
Despite the familiarity of the situation, one student (8) mistakenly thought the final temperatures would never quite equalize.

> (Would they [the final temperatures] still be different, or would they be the same?) I think they'd be a little bit different. The metal could be a little bit hotter still // 'cause the water was kind of colder and I don't think it's going to drop that far down. Like, it's not going to release all of its heat. 9: I3 8 (079-082)

Other subjects thought temperatures would oscillate around an intermediate value, or equalize at some arbitrary limit rather than at the ambient temperature.

> (What do you think it would be like in another few minutes?) Uh, the temperature of the thermometer would have dropped a couple of degrees and the metal would have dropped, too // (What would ... set the limit?) Probably zero // (Why do you think that would be a ... sort of limit?) 'Cause zero is when the, is the starting of the freezing point and the melting point ... of ice and water. 10: I3 7 (059-066)

Item 4: Mechanical truck



When is there an energy change?

a. from **A** to **B**
b. from **B** to **C**
c. from **C** to D
d. there is no energy change

source: Brook & Driver (1984)

Figure 5

Scientifically, the item invites description of energy transformation. Energy degradation due to friction as the truck slows down might also be mentioned. There are energy changes between all four illustrations. Potential energy of the truck increases from **a** to **b**, is transformed to kinetic energy from **b** to **c**, and is degraded into heat from **c** to **d**. It was anticipated that alternative conceptions might associate energy only with motion, or with the action of a person winding the truck. Substantive views of energy as a fuel and depository notions of the truck getting the energy it needs to move were also expected.

Subjects did not agree about the effect of winding the truck motor. One (6) believed that winding created a possibility (potential) that only became energy at the moment the truck was released. Two (1 and 4) thought that winding actualized potential energy that was already present in the truck, or changed it to a form that could result in motion. Two others (7 and 8) saw winding as establishing the proper conditions for energy to begin flowing through or accumulating in the truck. Two subjects (2 and 5) viewed winding as itself increasing the truck's energy.

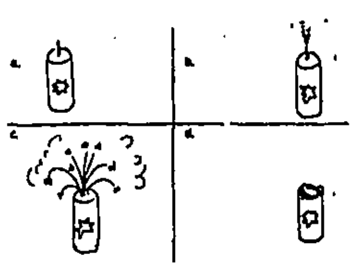
Several responses exemplified the functional view of energy as a generalized fuel, used up in the performance of tasks. One subject struggled with the thought that expended energy just ceases to exist.

> (What's happening with the energy as it's moving along, then?) Well, it's being used up, probably, from the wind and the ... friction, I guess // I just see it ... unwinding and the wheels are using that [energy] to make it go, I guess. (What happens as it's used up?) It just ... is, probably, no longer and it stops. It just ... I dont't know ... 11: I4 3 (076-081)

Other subjects expressed a flow-transfer orientation. For them, energy first moved into the truck and then moved out of it, becoming lost or unavailable, rather than nonexistent.

> ... As you're winding it, you'd be putting a little bit more energy in it, so it moves. And then when it slows down I think it's kind of losing its energy // it just kind of ... goes away. (Does it just vanish?) I think it just kind of mixes in with the air. And you can't tell it's there, but it is there. I think when you're winding it up, it's moving the stuff inside. And it's picking up more energy. (From where?) Outside, like ... from the air particles and everything. 12: I4 8 (084-098)

Item 5: Exploding firecracker



When does the firework have the most energy?

a. just before it is lit
b. just as it is about to go off
c. as it goes off
d. after it has gone off
e. There is no change in energy.

source: Watts & Gilbert (1982) (modified)

Figure 6

Scientifically, the situation is one of energy transfer and transformation. The potential (chemical) energy of the firework is dissipated during the explosion, primarily as heat. The most appropriate multiple choice response is A. It was expected that conceptions of energy as a reactive ingredient or a by-product of the explosion might surface, leading to response C. Associations of energy with motion would lead to the same response.

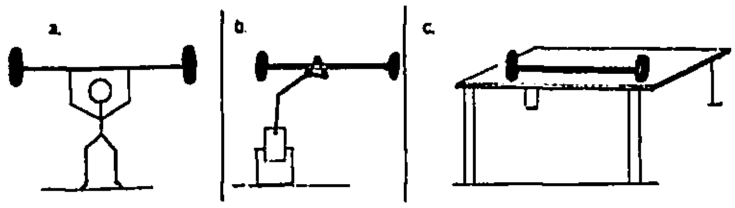
In fact, subjects did not restrain themselves to a literal reading of the question. Significant and varied roles were attributed to the burning wick. Three subjects (2, 5 and 7) saw its flame as adding energy to the firecracker, one (8) viewed it as releasing energy, and three (1, 4 and 6) thought it neither augmented nor diminished energy, but rather triggered energy changes.

> (What importance does the wick have in all of this?) It sets the change off. It's like winding the truck. It's going to set the change. 13: I5 4 (100-103)

In addition, there were different assessments of initial energy. Five subjects believed that energy was stored in the firecracker even before its wick was lit. A contrary view saw the firecracker, which initially lacked energy, as gaining it when the wick was lit. Two subjects (4 and 5) described energy as only potentially or partially present until triggered by the wick.

> When would you say it had the most energy?) When it was up in the air. When it was flying. (Explain why.) Because to get up in the air so quick and so fast you need lots of energy, and so c has to be where all the energy comes from. Well, the most part of the energy // Like, I don't know what makes it go off, like ... probably the flame makes it go off, so ... as soon as the flame gets down, then it all goes up in the air. So, it's both. Like there's energy from there [the burning wick] that makes it go up, so ... it's both of them. 14: I5 5 (134-139)

Item 6: Supporting a barbell



held by weightlifter | held up by machine | held up by the table

When does the bar have the most energy?
a. when it is held by the weightlifter
b. when it is held by the machine
c. when it is held up by the table
d. It has the same energy in each situation.

Source: Stead (1980) modified

Figure 7

The energy of the bar, in a scientific analysis, depends on its height, so the most appropriate response is D. It was expected that subjects who associated motion with animate objects would choose response A, and that those who adopted a functional view would view both A and B as correct.

The goal of the multiple-choice responses, to compare energy attributed to people, machines, and inanimate objects, was not met. All 7 subjects believed either that the bar's energy depended on its height, or that it was zero. Thus, all were able to chose response D (constant energy) without considering the nature of the barbell's support.

Subjects differed in their description of the energy associated with the barbell. A motion-centred conception was reflected by some (3 and 5) who focussed on the barbell's stillness.

(Does the bar have energy?) No // He's holding the bar up. But he's not moving it. So, if he was moving it then ... I don't know ... (But he's not. He's just holding it still.) OK. Well, then, I think he has all the energy. He has to hold the bar up, so he's got the energy. 15: I6 5 (150-155)

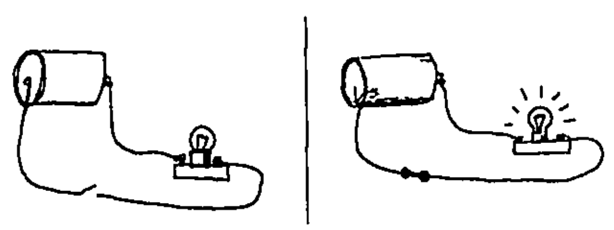
Subjects who did attribute energy to the barbell cited its height (1,2,4 and 6) or heat (8). In the latter view, energy appears as a by-product of heat flow.

The metal ... it could be attracting heat, and the heat's making energy inside of it // It's just the amount of heat it attracts that's creating the energy in it // 16: I6 8 (124-126)

A second difference concerned the fate of the person's energy. A substantive view was suggested by subjects who thought energy would be carried away by the person's sweat (7), be converted into heat (8), or move into the barbell (2 and 6). However, energy reduction was also described in less substantive terms.

(Is anything happening to his energy?) Yeah, it's getting tired. (Is it going somewhere?) No, it's just staying in one spot. Like, it's staying on his arms ... 17: I6 5 (156-159)

Item 7. Electric circuit



The battery is connected to the bulb but the switch is open.

Now the battery is connected to the bulb and the switch is down.

Which part of the circuit would you describe using the word **energy**?

source: Watts & Gilbert (1982)

Figure 8

A scientific description would mention the potential energy of the battery and its transformation in the bulb into light and heat energy. It was expected that descriptions would utilize a substantive, flow-transfer model. A depository view, in which the battery has energy which the bulb needs, was also anticipated.

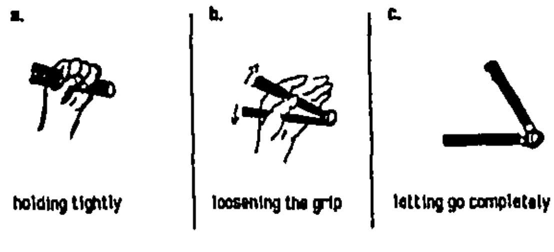
All responses were consistent with a flow-transfer orientation and involved something that originated in the battery and circulated around the circuit. The circulating 'substance' was most frequently identified as energy itself (2, 3, 5, 7, 8). However, several subjects distinguished (with some difficulty) between energy and a circulating carrier such as vibrations (1) or electricity (6).

> (Is there energy there?) It's in the battery. (How do you think of it?) I don't know. It's ... like they're sticking to something inside the battery. And then once the switch is on it ... just sort of has an opening and drains through the wire ... (What is it that's travelling there?) Energy. Electricity. (Is that the same thing?) Um ... no. Well ... in a way, yeah // Energy just isn't electricity. Energy is different ... things. There's different ... types of energy. Electricity is electricity.
> 18: 17 6 (123-126; 137-142)

The greatest variation in responses concerned what happens when the bulb lights. Subjects suggested that energy was being created (5), triggering a dormant potential of the bulb (4), being transformed (1 and 6), losing something that emerged as light (7), being carried away as heat (8), or being used up and vanishing (3 and 6). Energy was again described as a reactive ingredient, activated in the particular environment of the bulb.

> The negative energy or whatever is going into the light, into the socket, but it's not ... it doesn't do anything without the positive // (What happens if we close the switch?) The battery's giving off energy. [It's] just going to the light bulb and turning into heat energy and light energy. (Explain that a little bit more.) Energy's coming all the way through [the switch] to here [the bulb]. And from here [the other battery pole] to here [the bulb]. And they meet up and then it creates heat energy and light energy. And the light gives off them energies. The battery's losing energy. 19: 17 2 (162-166)

Item 8. Squeezing a grip strengthener



The athlete is squeezing the grip strengthener.
When is there an energy change?

a. from a to b
b. from b to c
c. from a to b and from b to c
d. There is no energy change.

source: original

Figure 9

Scientifically, there are energy changes as the "gripper" is being held (chemical energy being converted into heat in the squeezing hand), as it is released (potential energy of the spring being converted into kinetic energy), and while it springs open (kinetic energy being converted into heat and transferred to the surroundings). Response C is thus the most appropriate. Alternative conceptions might associate energy with animate objects or with motion, leading to responses B or C respectively.

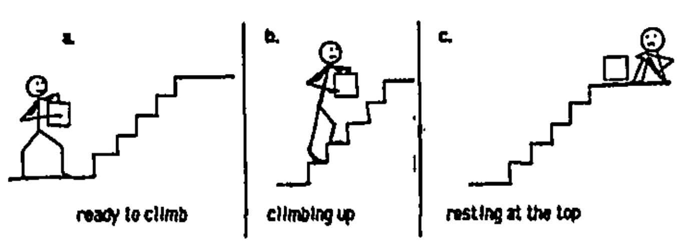
Introducing the discussion with an actual 'gripper' as well as by sketches, may have contributed to the comparatively lengthy and detailed responses. All subjects agreed that energy was present, even when there was no motion, and that it changed in some way as the gripper was released. A change in form (1 and 2), an increased amount (7), a decreased amount (3, 4 and 6) and a change in density (8) were all suggested.

I think some of the energy is letting loose in b ... as you're letting go, it's not held as tightly together. And the energy is kind of moving around more freely, and not as packed together as it was. So it's looser and has more places to go. So it's kind of ... moving out. 'Cause when you're packing it tightly together, it's all kind of ... bunched up, and it kind of just ... goes back into the handles more, and up into the ring [spring?]. Or else, it could be escaping and stuff.
20: 18 8 (172; 185-186)

Four subjects used heat in their explanations. Two (1 and 6) described energy conversions which developed heat in the hand of the person squeezing the gripper. Two others (7 and 8) reversed the process and described heat as a source of energy. Three subjects (2, 3, 7) expressed an undifferentiated view which associated or equated energy with a force or pressure necessary to overcome the resistance of the gripper.

The spring's got potential energy which stays constant once it's closed. Your hand's giving off energy to keep it closed // It repels, like, the force of the spring, so it equals out. There's no [net?] force right now, 'cause nothing's moving.
21: 18 2 (180-182)

Item 9. Carrying a load up stairs



Where is there an energy change?
a. from a to b
b. from b to c
c. from a to b and from c to d
d. There is no energy change.

source: Stead (1980) modified

Figure 10

A scientific analysis sees energy transformation from a to b (potential chemical energy from the person's food to kinetic energy and heat) and from b to c (kinetic energy to increased gravitational energy). The most appropriate response is thus C. Alternative conceptions of energy as associated with animate objects, motion, and the performance of useful tasks were anticipated. Descriptions of energy as a state, rather than a substance, were also expected.

Different views were expressed about changes in the quantity of energy as the stairs were climbed. One subject (1) maintained that it did not vary. Others suggested that an initially large amount of energy was being tapped for the climb, decreasing steadily (7) or decreasing and then being restored as the climber rested at the top of the stairs (3 and 8). Alternatively, the initial amount of energy was also described as low (or zero). One subject (2) saw the maximum amount of actual energy becoming available instantly, as soon as the climb began and then being converted to a potential for energy. A more functional orientation described energy as present only (or primarily) while the climber performed his task.

> It goes from low, and when he's walking up the stairs it goes up a bit, and when he rests his energy goes back down 'cause he's not doing anything. // (Where does this extra energy come from?) Um ... from the food he ate. (What starts it coming out?) Um ... I guess your mind. Like, you see the stairs coming so you kind of know that you're going to have to use energy to walk up the stairs. So I guess you just, you sort of tell yourself that you've got to walk up the stairs and kind of get some energy.
> 22: I9 6 (170-174)

A second clear divergence of interpretations concerned whether energy could properly be associated with the box. Two subjects (1 and 2) believed it could; two (6 and 7) expressed no clear opinion, and two (3 and 8) expressed an animate view in which the box had nothing to do with energy.

(What about the load?) // I don't know. It's hard to say that there's energy in something that's not moveable. (What about on the stairs being carried up? In a way it's moving there.) Yeah, well, not itself. Like, it's being held by something else.
23: 19 3 (172-175)

As in item 8, energy was closely associated with heat or sweat in several descriptions (1, 3, 7, and 8).

Survey Results

Overview

Survey items are reproduced and analyzed below. Quotations are identified by subject number, which is keyed to the student's level and class in Table 8, below.

Table 8. Survey Identification

Class Code	Class	Group Size	Survey Numbers
9	Science 9		
	- class E	17	1 - 17
	- class F	22	18 - 39
11G	General Science (Grade 11)	15	40 - 54
11B	Biology (Grade 11)	19	55 - 73
11P	Physics (Grade 11)	11	74 - 84

An additional survey, number 0, was partially completed and of uncertain origin.

Response patterns for all multiple choice items except #6 were significantly different from chance (one group chi-square, $p < 0.001$). This suggests that students took the survey seriously, not treating it as a multiple guess task, and that they found some basis for their answers other than whimsy. Item 6 was used in two slightly different forms, having been modified after administration to the physics 20 class, so no statistical analysis of its results was attempted.

A number of findings emerge from the data and appear worthy of comment.

1. Survey responses showed evidence of many previously identified alternative conceptions. Responses designed to appeal to non-scientific conceptions had considerable appeal, as shown in Table 9.

Table 9. Non-scientific Conceptions Illustrated by Survey Responses

Item	Conception					
	Animate	Motion	Useful task	Depository	Flow/ transfer	Ingredient/ byproduct
4a	20 of 84					
4b		20 of 84				
5c		58 of 85				
6a	24 of 80					
7a						13 of 75
7b						6 of 75
7c					7 of 75	
7e						2 of 75
8a	24 of 80					
8b		15 of 80				
9a			20 of 81			
9b					18 of 81	
9c					12 of 81	
9d				27 of 81		
10a				16 of 80		
10b		12 of 80				
10c				19 of 80		
10d		17 of 80				
Totals	68 (28%)	122 (30%)	20 (25%)	62 (26%)	37 (16%)	21 (9%)

2. Differences in response patterns between classes were statistically significant ($p < 0.05$) for items 2, 5 and 9, and were on the borderline of significance for item 10. This small degree of difference was not unexpected in view of previous findings suggesting the stability and pervasiveness of alternative conceptions. The cause of the differences cannot be determined from existing data.

3. Compared to previous findings, the open response question (#1 - open refrigerator) produced an unexpectedly large proportion of answers which described the situation specifically in terms of energy (25%). This contrasts with the interviews and Duit's (1990) report that energy was seldom used spontaneously as a descriptive concept for similar situations. It is possible that particular circumstances, such as open refrigerators and empty rooms with lights on, have been linked in common parlance to energy-based descriptions, most likely by conservation programs. Such linkages need not imply any appreciation of the underlying nature of the situation. Subjects might fail to employ similar energy-based descriptions in different circumstances, such as those portrayed in the interview or Duit's study, even though the concept appears equally applicable.

An additional 45% of responses referred to heat or heat loss without explicitly describing them as forms of energy. It was not possible to determine from the data whether these responses implied an energy-based view of the refrigerator.

4. Grade 11 physics students tended to chose the largest proportion of scientifically acceptable answers. This was true for five of nine questions which contained multiple choice responses which clearly exemplified a scientific conception

(Table 10). More generally, grade 11 students, who had received more science instruction than grade 9 subjects, also chose a larger proportion of "scientific" answers. The sample was not large enough to justify more sophisticated statistical treatment. It must be remembered that, although some more advanced students make greater use of scientific concepts, alternative conceptions are not abandoned (finding 1, page 112) and were still preferred in most situations (finding 2, page 113).

Table 10. Scientifically Acceptable Responses

Item	Frequency by Class				% Frequency by Class			
	9	11G	11B	11P	9	11G	11B	11P
2 b or c	6 of 39	8 of 15	9 of 18	8 of 11	15	53	50	73
3 c or d	13 of 38	9 of 15	6 of 19	6 of 10	34	27	32	60
4 c or d	17 of 35	9 of 15	13 of 19	5 of 11	49	60	68	45
7 d	16 of 34	8 of 15	13 of 16	10 of 10	47	53	81	100
8 d	13 of 38	6 of 14	9 of 18	7 of 10	34	43	50	70
9 c	1 of 39	3 of 15	6 of 17	2 of 10	3	20	35	20
10 e	5 of 38	2 of 15	3 of 18	6 of 9	13	13	17	67
				mean (%)	29	38	48	62

5. Justifications almost always treated energy in substantive terms. The physicist's abstract conception of energy as a convenient numerical quantity calculable for any system whatsoever was seldom in evidence. Only in connection with people did "energy" sometimes have the sense of "an energetic state", and this was a limited usage which tended to be differentiated from descriptions of non-human energy.

> With the person holding the book it is human energy, but when a machine lifts, it's energy produced by electricity or whatever the machine runs on ... 35: S6 27

6. Reference to energy degradation was conspicuous by its absence. Situations in which energy clearly "runs down", such as the coasting bicycle (item 4), the exploding balloon (item 5), pushing a box (item 9) and the swinging pendulum (item 10) did not elicit any responses which indicated a general appreciation that energy is degraded or dissipated during the performance of useful work. Unfortunately, this aspect of a scientific energy concept is not merely an elegant, albeit abstract thermodynamic tidbit. It provides an essential conceptual foundation for programs of energy management and conservation, and could thus be of considerable practical importance.

7. The labels "kinetic" and "potential" were used frequently, but not necessarily scientifically. Because of the researcher's realization that "potential" could have the sense of "capacity for" energy (a result of the interviews), use of these two terms was not of itself taken to indicate a scientific energy conception.

8. As in the interviews, heat was invoked as a carrier or mediating agent for energy (item 7). This suggests a limited, substantive view of energy. Similarly, some responses to item 8 treated energy as only one of several possible causes of action

> A machine has no life, so it should need no energy. It runs on gas or electricity. No energy is needed for the machine. 36: S6 33
>
> The only reason the ball rises is because of density, not energy. 42: S8 17
>
> [There is] only buoyancy, and I'm not sure if that is considered energy. 43: S8 32

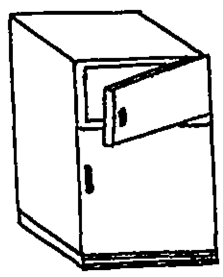
9. Energy was not clearly differentiated from related concepts like force, pressure, and momentum.

> The force of energy being used to keep the ball and the particles inside the ball held down is by the human. 44: S8 30

Detailed Discussion of Responses to Survey Items

Each survey item is reproduced below with a summary of its intent, a brief scientific analysis of energy in that situation, and a discussion of student responses.

Item 1. Open Refrigerator



The freezer door on the refrigerator has come open.
Describe as much as you can about what is happening in this situation.
source: original

Figure 11

Table 11. Survey Item 1 Response Summary

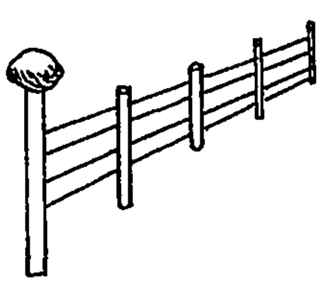
Response	Totals		Frequency by class			
	n	%	9	11G	11B	11P
energy not mentioned	25 of 83	30	15 of 38 (38%)	4 of 15 (27%)	2 of 19 (11%)	4 of 11 (36%)
heat or hot air loss	37 of 83	45				
energy mentioned explicitly	21 of 83	25				
-unrelated to heat loss	2 of 83	2.4				
-related to heat loss.	12 of 83	14.4				
-fridge works harder	7 of 83	8.4				

Subjects were confronted with a familiar situation that was easily described in terms of energy but were given no cues that this perspective would be appropriate.

Nevertheless, over 2/3 of the subjects made explicit mention of specific or general concepts of energy in their descriptions. This proportion was lowest in the grade 9 and physics classes and highest in the biology class. The most common response involved energy loss, or energy being released (40, 56, 60, 63, 69). Apparently the energy used to operate the freezer was seen as placing it in a high-energy state which was jeopardized when the door was opened. The majority of descriptions focussed on a particular energy form (heat) and were framed in concrete terms: 16 subjects mentioned the escape of cold air, and another 16 coupled that with an inrush of warm air.

This item was intended to parallel interview item 1 (house with open door). The widespread use of energy concepts in survey responses stands in sharp contrast to the interview, in which no subject mentioned energy. No explanation for this divergence is apparent.

Item 2. Rock on Fencepost



The rock is balanced on top of the fencepost.
Which statement gives the best description of **energy** in this situation?

a. There is no energy here.
b. The rock has more energy on top of the post than if it were lying on the ground.
c. The rock and post(and the earth below them) have more energy than if the rock were lying on the ground.
d. The energy of the post is being used up holding the rock.
e. The energy of the rock and post (and the earth below them) is being used up holding the rock.

source: Stead (1980) modified

Figure 12

Table 12. Response Summary for Item 2

Class	Response Frequency					Total	Response Percentage				
	a	b	c	d	e		a	b	c	d	e
9	18	4	2	9	6	39	46	10	5	23	15
11G	3	8	0	0	4	15	20	53	0	0	27
11B	4	9	0	2	3	18	22	50	0	11	17
11P	1	8	0	0	2	11	9	73	0	0	18
total	26	29	2	11	15	83	31	35	2	13	18

significance of response patterns: $p = 0.0041$

Response A was intended to differentiate between conceptions which link energy to change, motion or human agents, and progressively more general scientific conceptions (responses B and C). Responses (D) and (E) were designed to appeal to undifferentiated conceptions which equate energy with force necessary to hold the rock in what might be seen as an unnatural position.

Differences in response patterns were significant ($p = 0.0041$). Almost half the grade 9 students saw no evidence of energy (response a), compared to less than 1/4 of the grade 11 students, and only 9% of the physics students.

> These are non-animated, non-living things. The are not being crashed together to create any sort of fusion or energy. They just sit there. 24: S2 33

However, even though high-school students were more willing to interpret this static, inanimate situation in terms of energy, their justifications showed a variety of conceptual orientations which are far from orthodox scientific ideas. Two contrasting viewpoints are especially evident:

(1) motion (falling) is the natural state for a raised object, but this can be prevented by a resisting energy.

> If the post was flimsy with no strength, the rock would fall. In order for the rock to stay, the post has to have energy. 25:S2 20

(2) balanced objects (or those on the ground) are naturally at rest, but can acquire energy by falling.

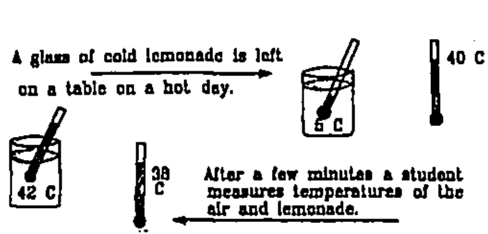
> There is no energy if the rock doesn't fall. If it falls, gravity might give it energy. 26: S2 5

Students who saw energy as being expended did so in general terms, associating it with all parts of the system (response e) more frequently than with the post alone (response d). The post was seen as transmitting energy from the earth to the rock.

> Energy has to come from the earth in order to hold the fence post up, and from the post to hold the rock in place. 27: S2 55

This item was intended to parallel interview item 2 (car on hoist). Both sets of responses did link energy to motion and to the process of maintaining an object in a raised position. However, the fact that a hoist needs a motor to raise it, and the motor uses energy, introduced an unforseen complication to the interview situation.

Item 3. Lemonade



The student must decide whether the measurement is reasonable. What is most important in making that decision?

a. The lemonade would not warm up so much in just a short time.
b. The air near the glass would cool down more as the lemonade warms up.
c. The two temperatures would end up equal.
d. The lemonade would never get hotter than the air around it.
e. The measurement seem reasonable, but it would be sensible to repeat it just to make sure.

source: Duit (1990) modified

Figure 13

Table 13. Response Summary for Item 3

Class	Response Frequency					Total	Response Percentage				
	a	b	c	d	e		a	b	c	d	e
9	7	5	4	9	13	38	18	13	11	24	34
11G	5	3	1	3	3	15	33	20	7	20	20
11B	1	6	2	4	6	19	5	32	11	21	32
11P	0	2	1	5	2	10	0	20	10	50	20
total	13	16	8	21	24	82	16	20	10	26	29

significance of response patterns: $p > 0.05$

The question situation was deliberately chosen to be familiar, in order to evoke lifeworld frameworks without specifically cuing them. From a scientific viewpoint, energy degradation, transfer, and conservation are particularly relevant to this situation. However, science classes are unlikely to have provided explanatory vocabulary and concepts directly. Although examples of heat transfer should have been familiar to all students from their grade 9 studies, discussion of energy degradation is not a required topic, and energy conservation is introduced in other contexts.

The most scientifically correct responses are C and D. A and B are not incorrect, but bear less directly on the question.

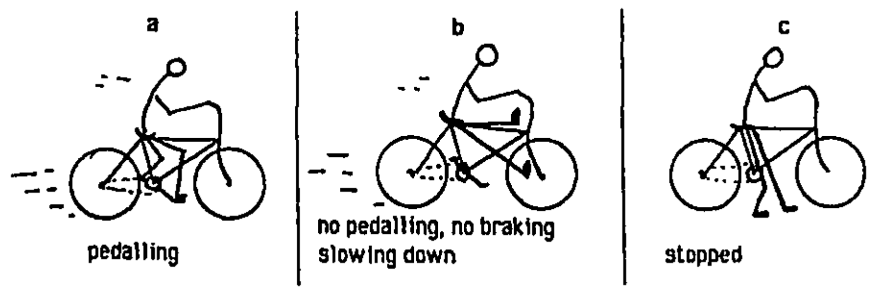
There was no significant difference in the response distribution between classes. However, the physics 20 students gave about double the proportion of scientifically acceptable answers (c or d) compared to the other groups (60% compared to 31%). Only 13% (11 of 82) explanations mentioned energy; all but 3 of them were from physics students. No explanations involved the idea of energy degradation. Only 2 responses (both from physics students) made specific mention of energy conservation.

A variety of other explanations were proposed, but were not well clustered in support of particular multiple choice responses. Apparently the responses provided do not tap consistent patterns of reasoning, if such patterns do exist for this situation.

The item was designed to parallel interview item 3 (hot metal in cold water). It was less successful in eliciting discussions of heat energy. Many students focussed on the idea of 'coldness', which was described quite substantively.

> The glass is letting off cold particles which turn the air around the glass cold. The glass is getting warmer as this is happening. 28: S3 38

Item 4. Bicycle



The rider stops pedalling. The bike coasts along, slows down, and stops.
Where are there energy changes?

a. from **A** to **B**
b. from **B** to **C**
c. from **A** to **B** and from **B** to **C**
d. There are no energy changes.

source: Stead (1980) modified

Figure 14

Table 14. Response Summary for Item 4

Class	Response Frequency				Total	Response Percentage			
	a	b	c	d		a	b	c	d
9	12	10	15	2	39	31	26	38	5
11G	3	3	9	0	15	20	20	60	0
11B	4	2	13	0	19	21	11	68	0
11P	1	5	4	1	11	9	45	36	9
total	20	20	41	3	84	24	24	49	4

significance of response patterns: $p > 0.05$

The question was designed to evoke conceptions which define energy in terms of human activity or of motion. It is thus an inverse of question 2, which involved neither motion nor animate objects. In addition, it provides an opportunity to explain answers in terms of energy transformations.

Response C is most correct scientifically. Response D is also acceptable in the limited sense of an unchanged total quantity of energy. Responses A and B are each incomplete from a scientific viewpoint.

There was no significant difference in the pattern of responses for different classes. However, an unexpectedly high proportion of physics students chose response B, compared to the other high school groups (45% compared to 20% and 11%).

Three students maintained that there were no energy changes (response D), but this did not necessarily arise from an orthodox view of energy conservation. Rather, it was an outcome of an equilibrium between energy supply and demand.

> The person has to use his energy to push the bike, but the more harder it is, the more energy you need. If you were pedalling up a hill you would need lots of energy.
> 29: S4 9

Many students offered explanations which referred to particular frames in the question illustration, rather than to changes between them. It would be clearer to letter the transition between pedalling and coasting as **a** and that between coasting and stopped as **b**. Nevertheless, explanations fell into easily identifiable groups.

For many students, energy was identified only with activity by the rider. A second group identified energy with any motion, and often quantified energy according to speed. However, this view often differed from the scientific conception of kinetic energy. Rather, the bike was apparently regarded as something which needs a continuing supply of energy-fuel in order to keep moving (depository framework).

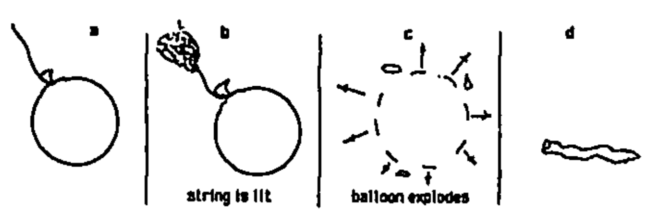
> The bike begins to slow down because of a decreasing supply of energy. 30: S4 68

A final group of students distinguished between two forms of energy, often using the words "kinetic" and "potential", but identified the former with energy release (pedalling) and the latter with storing up or loss of energy (coasting and stopping).

> The energy of moving is kinetic because something is being used a lot. But the energy of coasting and stopping is potential because the energy is being stored.
> 31: S4 44

The question was designed to parallel interview item 4 (mechanical truck). Both items provoked similar idiosyncratic usage of the terms 'potential' and 'kinetic' and revealed a view of energy as a sort of fuel, used up or called upon when something moves.

Item 5. Exploding Balloon



The string burns and the balloon explodes.
When does the balloon have the most energy?

a. before the string is lit
b. after the string is lit
c. as it explodes
d. after the explosion
e. The energy stays the same

source: original

Figure 15

Table 15. Response Summary for Item 5

Class	Response Frequency					Total	Response Percentage				
	a	b	c	d	e		a	b	c	d	e
9	4	5	29	1	0	39	10	13	74	3	0
11G	1	1	12	1	0	15	7	7	80	7	0
11B	3	4	12	0	0	19	16	21	63	0	0
11P	1	1	5	0	3	10	10	10	50	0	30
total	9	11	58	2	3	83	11	13	70	2	4

significance of response patterns: $p < 0.05$

The question was designed to elicit conceptions of energy as a fuel or causal agent, or as a byproduct of changes. A focus on motion would lead to response C. Students regarding the situation from a scientific orientation were expected to discuss energy conservation or transfer.

However, students interpreted the question as referring variously to the balloon alone, the balloon and string, and the system of balloon, string and surrounding air. Therefore, responses B and C, A, and E, respectively, could be justified scientifically. In fact, the great majority of students chose response C. The response patterns of the different classes were significantly different and justifications fell into the expected patterns.

Many students viewed energy as a fuel for the explosion. One student restricted this energy-fuel even more, associating it only with useful human activity (Watts' functional framework):

> It has more energy after the string is lit, because the fire is a means of warmth to the people around it. There is no energy when it blows up, because it is of no use except to scare people, which causes them to jump and use energy of their own. 32: S5 4

Energy was also seen as a reactive agent, dormant or stored in the balloon before the explosion.

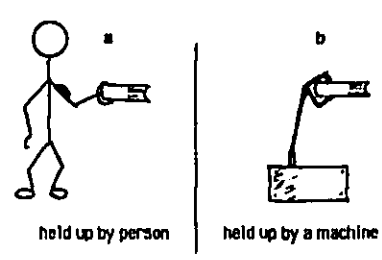
> All the balloon particles fly outward. So does the energy from inside, and the energy is pushed so hard and fast [that] more energy is released, because of the flame hitting the balloon. 33: S5 23

A large group of subjects proposed that the explosion created energy (Watts' by-product framework).

> As it explodes, all the forces inside the balloon are let out and converted to energy. 34: S5 81

This question was intended to parallel interview item 5 (exploding firecracker). Responses to the two items were very similar. In each, subjects assigned a similar variety of roles to the flame in augmenting, releasing, or triggering energy changes. Both questions provoked disagreement over the initial presence or absence of energy in the balloon.

Item 6. Holding a book



In which situation is there the biggest energy change?

a. when the book is lifted up by the person
b. when the book is lifted up by the machine
c. The energy change is the same for both ways of lifting.
d. There is no energy change when the book is lifted..

source: Watts & Gilbert (1982) modified

Figure 16

Table 16. Response Summary for Item 6

Class	Response Frequency				Total	Response Percentage			
	a	b	c	d		a	b	c	d
9	20	12	5	0	37	54	32	14	0
11G	7	3	5	0	15	47	20	33	0
11B	8	2	7	2	19	42	11	37	11
11P	*	*	*	*		*	*	*	*
total	35	17	17	2	71	49	24	24	3

* Class 11P did not receive the same question wording as the other groups.
significance of response pattern: p not calculated

The question was designed to directly contrast a person and an inanimate device, both performing the same useful task involving movement (lifting a book). It was expected that concepts of energy as unique to animate objects would be distinguished from those which visualize it as a generalized fuel. Students with a scientific orientation were expected to link energy required with the height to which the book is lifted, rather than the lifting agent. Response C is most acceptable scientifically, at least if the comparative efficiency of the person and the machine is ignored or considered equal.

The question was modified after the initial trial with physics 20 students. Therefore, their responses are not included in the tally, although their explanations were analyzed. Thus, significances cannot be calculated on the same basis as for the other questions. However, answers were well distributed between responses A, B, and C. Response D was included for symmetry and was chosen only twice.

There was a clear difference between justifications for response C, which tended to focus on the book as the receiver of the action, and those for responses A and B, which focussed on the agent doing the lifting. Many students clearly explained that "mechanical energy" is different than "human energy" in kind, not just in form.

> With the person holding the book it is human energy, but when a machine lifts, it's energy produced by electricity or whatever the machine runs on ... 35: S6 27

Some subjects regarded human agents as displaying "real" energy; they could thus speak of energy of both humans and machines while maintaining a basically animate framework for the concept. A second group considered mechanical energy as more "real", thus preserving a functional framework. Still others categorically restricted energy to either living beings or machines.

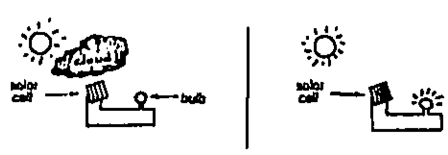
> A machine has no life, so it should need no energy. It runs on gas or electricity. No energy is needed for the machine. 36: S6 33

> The stick guy isn't using energy. He just locked his bone structure up to hold the book. 37: S6 11

> The machine is mechanical. Sure, it's using energy, but it would take more strength for the man to hold it up. The machine doesn't feel. 38: S6 41

The situation was designed to parallel interview item 6 (supporting a barbell). However, the revised wording of the survey item focussed attention on energy change, rather than total amount of energy of the object. Perhaps as a result, the survey item was much more successful in producing a range of multiple choice responses.

Item 7. Solar cell



The solar cell is connected to a light bulb, but a cloud shades it from the sunlight. [Now] the cloud has moved and the bulb lights. Which description best fits your idea of energy in this situation?

a. Sunlight releases the energy of the solar cell, so the bulb lights up.
b. Electricity produced by the solar cell makes the bulb release its energy and light up.
c. The electric current in the circuit gets "charged up" with energy in the solar cell and carries it to the bulb, which lights up.
d. Light energy from the sun is changed into electrical energy by the solar cell and then back into light energy by the bulb.
e. Electrical currents from the solar cell go through both wires, meet in the bulb, and react to produce light energy.

source: original

Figure 17

Table 17. Response Summary for Item 7

Class	Response Frequency					Total	Response Percentage				
	a	b	c	d	e		a	b	c	d	e
9	9	3	5	16	1	34	26	9	15	47	3
11G	4	2	0	8	1	15	27	13	0	53	7
11B	0	1	2	13	0	16	0	6	13	81	0
11P	0	0	0	10	0	10	0	0	0	100	0
total	13	6	7	47	2	75	17	8	9	63	3

significance of response pattern: $p > 0.05$

The question was designed to explore various notions of energy as a substance which changes over time (Watts' substantive framework). Response D is most acceptable scientifically and was chosen by a large proportion of subjects (63%), with no statistically significant difference in response patterns between classes. An unexpected feature of several of the written explanations was the use of heat as an element in whatever transformation or other process was being proposed.

> The sun gives off heat, and heat causes energy.... 39: S7 20

> The solar cell needs sun or heat for it to work, and when the sun shone on it, it heated up the wires electrically, which lit the bulb. 40: S7 41

Unfortunately, the item appears to have three major flaws. First, the multiple-choice alternatives need to be simplified. This is suggested by the large number of written responses which offered a justification that did not clearly support the chosen response. It is likely that the rather subtle distinctions between the multiple choice alternatives, often dependent on only a few words, were not noticed or pondered. Therefore, the alternative responses are considered to require simplification and clarification.

Secondly, the diagram needs to be redrawn so that the solar cell appears to face the sun, not the light bulb. Several students described perpetual motion machines based on the diagram provided.

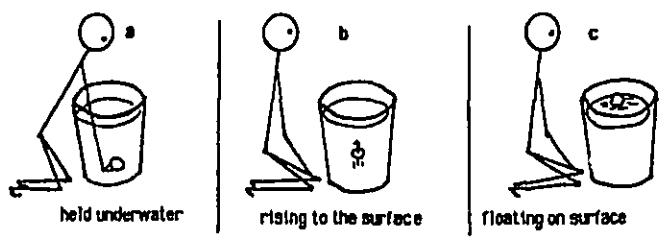
> What sun does get to the cell makes energy to run the light bulb. Then the light bulb keeps itself going by lighting the solar cell. 41: S7 11

Finally, the alternative responses need to be more clearly focussed on a specific aspect of the circuit which is likely to elicit alternative conceptions. All the physics students, about 4/5 of the biology students, and half the grade 9 and science 24 students chose the scientific response (D). Differences in response patterns between classes were not significant.

It is not clear why the orthodox response was so widespread. Only the science 24 students were likely to have encountered electrical circuits in their science classes.

The majority of male students would have constructed simple circuits in grade 8 Industrial Education class, but without much theoretical consideration. The parallel interview item (question 7, electrical circuit) elicited a greater variety of energy descriptions, although not the association with heat.

Item 8. Submerged ping-pong ball



The person lets go and the ping-pong ball pops to the surface.
What part of this situation could be described using your idea of energy?

a. Only part a where the person is forcing the ball to stay underwater.
b. Only part b, where something is moving.
c. Only part c, where the ball is at a higher level and the person is (a little bit) tired.
d. My idea of energy applies to more than one part.
e. There is no energy here at all.

Source: Watts & Gilbert (1982) modified

Figure 18

Table 18. Response Summary for Item 8

Class	Response Frequency					Total	Response Percentage				
	a	b	c	d	e		a	b	c	d	e
9	11	10	1	13	3	38	29	26	3	34	8
11G	5	2	1	6	0	14	36	14	7	43	0
11B	7	1	0	9	1	18	39	6	0	50	6
11P	1	2	0	7	0	10	10	20	0	70	0
total	24	15	2	35	4	80	30	19	3	44	5

significance of response pattern: $p > 0.05$

The question was designed to directly contrast those conceptions of energy which centre on motion (response B) and those which see people (or animate objects) as central (response A). It also contrasts such one-feature characterizations of energy with more complex conceptions (responses C and D). It was expected that confusion of energy with force would be stimulated by the wording of response A ("...the person is forcing the ball to stay underwater.")

Response D is scientifically acceptable. Response E is scientifically incorrect, and responses A, B and C are of insufficient scope to be complete.

There was no statistically significant difference in the pattern of responses from different classes. Nevertheless, there is a noticeable shift towards response D in the high school classes, reaching 70% for physics students. By contrast, biology students showed a greater tendency than physics students to choose response A, which associates energy with human activity (38% compared to 10%).

The expected contrast between motion-centred and animate-object based conceptions of energy was observed in the justifications. In addition, several responses contrasted energy with other causes of action. Energy was portrayed as just one possible trigger or fuel rather than being used as a general way of analyzing physical situations.

> The only reason the ball rises is because of density, not energy. 42: S8 17
>
> [There is] only buoyancy, and I'm not sure if that is considered energy. 43: S8 32

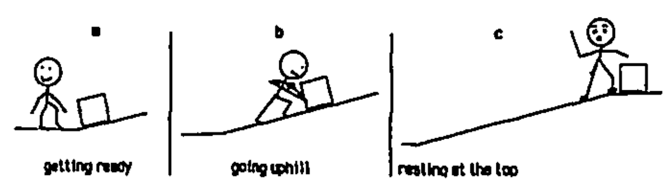
As previous investigators have noted, student explanations sometimes do not distinguish clearly between energy, force, and related terms.

> The force of energy being used to keep the ball and the particles inside the ball held down is by the human. 44: S8 30

> The person is exerting energy on the ping-pong ball. The ball is absorbing energy until it is released... (emphasis added) 45: S8 60

This question is somewhat parallel to interview question 8 (grip strengthener), which provided ideas for the specific responses in the survey question. In both cases, the expected confusion of force, work and pressure was evident. Heat was prominent in the interview discussions but absent from the survey responses. Although neither question demonstrated serious flaws, their difference in focus obviates any direct comparison of responses.

Item 9. Pushing a box uphill



The person pushes the box uphill and then sits down to rest.
Which description best fits your idea of the **person's energy** as the box is pushed up the hill?

a. energy is being produced in the person's body so the work can be done.
b. Energy is being transferred from the person into the box.
c. Energy is being shared between the box, the surroundings, and the person's body.
d. Energy is being used up pushing the box.
e. My idea of the person's energy is different from all of these.

source: Watts & Gilbert (1982) modified

Figure 19

Table 19. Response Summary for Item 9

Class	Response Frequency					Total	Response Percentage				
	a	b	c	d	e		a	b	c	d	e
9	14	6	1	15	3	39	36	15	3	38	8
11G	3	6	3	3	0	15	20	40	20	20	0
11B	1	2	6	8	0	17	6	12	35	47	0
11P	2	4	2	1	1	10	20	40	20	10	10
total	20	18	12	27	4	81	25	22	15	33	5

significance of response pattern: $p < 0.05$

The item deliberately focusses on the person's energy in order to elicit everyday associations with strength and force. Response A localizes energy to the person and views it from a functional framework as necessary for the performance of a useful task. Response B was intended to elicit flow-transfer frameworks, as was response C. Response D is compatible with views of energy as a fuel.

The most scientifically acceptable response is C, which is compatible with ideas of energy transfer, degradation and conservation. Response B is more limited, as it does not include the environment. Responses A and D are commonplace descriptions which are not scientifically accurate: strictly speaking, energy is neither produced nor used up.

Differences in the response pattern between classes are statistically significant at 0.05 level ($p = 0.013$). Choices were well distributed across responses A to D. The small number of students (4) choosing response E suggests that the other choices were acceptably comprehensive. Unfortunately, many "explanations" supplied less insight than was hoped into the subject's underlying reasoning. Perhaps the explanatory nature of the multiple-choice responses reduced the answering task to one of identification, so subjects felt less need to create individualized models of the situation.

The wording of the item could likely be improved. Only a small proportion of physics students chose response C, which was intended to reflect the scientific view most completely. The wording "energy is being shared" may be at fault. A possible alternative, which is also more parallel to responses A and B, would be "Some of the person's energy is being distributed between the box and the surroundings."

The expected confusion between energy and force was observed in only a few instances.

> The force the person supplies to the box is where energy is given off.... 46: S9 50

More common was the everyday equation of strength with the presence of energy (or an energetic state) and tiredness with its absence.

> When you push something, you get tired creating energy. 47: S9 16

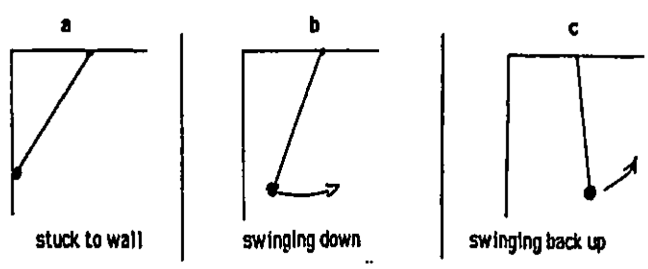
Three subjects explained the choice of response (d) (energy is being used up) with the term "exerting" energy.

> The man has to exert his own physical energy to push the box up the hill. 48: S9 55

This explanation appears to reflect identification of energy with force or overcoming resistance. Also, rather than suggesting that energy is "used up" or consumed, it has the sense that energy is "utilized". That is, energy is a required element in the process, but not necessarily one that is expended. It could be conserved, transformed, transferred, or just act like a catalyst.

Survey item 9 depicts a similar situation to interview question 9. However, the survey item focusses more specifically on the person's energy, using ideas elicited from the more general interview question. Several features of the interview responses, including the amount of energy possessed by the box and the role of heat in energy changes, are not tapped by the survey question.

Item 10. Pendulum



The glue breaks, and the pendulum swings down and then up again.
If we measured the pendulum's energy, our answer would

a. be highest in a and go steadily down as the pendulum swings
b. be lowest in a and go up as the pendulum gathers energy to swing
c. be high in a, go down as the pendulum swings lower, and then go back up in c
d. be low in a, go up as the pendulum swings faster, and then go back down in c
e. stay the same in a, b, and c

source: Duit (1990) modified

Figure 20

Table 20. Response Summary for Item 10

Class	Response Frequency					Total	Response Percentage				
	a	b	c	d	e		a	b	c	d	e
9	7	8	11	7	5	38	18	21	29	18	13
11G	3	3	4	3	2	15	20	20	27	20	13
11B	6	1	3	5	3	18	33	6	17	28	17
11P	0	0	1	2	6	9	0	0	11	22	67
total	16	12	19	17	16	80	20	15	24	21	20

significance of response pattern: $p > 0.05$

The question was designed to probe the role of energy in creating and sustaining motion. Response A embodies the idea that motion continually uses energy (fuel focus). Response B suggests that energy is released or created in order for something to happen (functional focus). Response C involves the expenditure and replenishment of energy (depository focus). Response D associates energy with speed (motion focus). Response E was intended to cue explanations involving energy conservation and/or transformation.

The most scientifically acceptable response to a literal reading of the question is E. Other responses can, however, be scientifically justified if the question situation is appropriately limited or extended. If energy is restricted to potential or kinetic, respectively, responses C or D become acceptable. If the oscillation of the pendulum is imagined to continue until it eventually dies away, response A is scientifically appropriate.

Some confusion was caused by the difference in height of the pendulum bob in sketches a and c. Sketch c could be revised to show the pendulum at its maximum height. Also, several students extended the question to more than one oscillation, sometimes considering the effects of air resistance and the resulting slow decrease in amplitude. These complications were not intended to be introduced, and might be avoided by a more precise question wording, such as "If we measured the energy of this system at different points in its first swing, our answer would ...."

Differences in the response patterns of different classes approached significance at the 0.05 level ($p = 0.06$, chi-square). There was a noticeable shift towards the scientific view in physics students (67% chose response E, compared to an average of 14% in the other classes). Inasmuch as physics 10 and 20 stress the historical development of conservation laws for motion, physics students are likely to have considered pendulums in this context. Also, biology students showed a relatively high tendency to interpret motion in terms of continuous energy use (33% chose response A, compared to an average of 20% in the other groups).

Explanations of answer choices showed several clear divisions. There were two distinct views of energy when the pendulum was glued to the wall. One interpretation held that this required a lot of energy; oscillation of the pendulum, by contrast, was a more natural state requiring little or no energy. An opposing view was also expressed: the stuck pendulum has no energy, but oscillation requires it.

> It takes more energy for the pendulum to stay glued than to swing back and forth - it (swinging) takes energy, but not as much. 49: S10 65

> It wouldn't need any energy to be stuck to the wall, but it would need some to break through all the molecules in the air. 50: S10 37

A number of students linked energy with momentum. Only physics students would likely have received a formal introduction to the scientific view of momentum, so others probably used the term in an everyday sense that remains unexplored.

Some responses suggest that "real" energy is present only when something is being accomplished. Potential energy, in this sense, apparently is taken to mean "potential to have or contain energy." "Using energy" may thus imply generating or gathering, as well as expending it. Alternatively, if energy is regarded as a characteristic rather than a substance, "using energy" can be taken as meaning "acting energetically." "Potential energy" could thus have the sense of "the ability to be energetic".

> It doesn't take energy to sit, but when something is moving is (it?) uses energy. So when the pendulum swings down and comes back, it is using energy. 51: S10 20

> It would only have potential energy in (A) (stuck to the wall). In (B) it gains energy as its speed increases. In (C) its energy would decrease because its speed decreases as well. 52: S10 74

The question is quite parallel to interview item 10 (ball on track). Although the alternatives in the interview item concern distance, consideration of energy was prompted by the interviewer. Responses to the two items were similar, with disagreement over the initial energy of the objects, the reality of potential energy, and the need for energy to prevent or cause motion.

Consistency of Subjects' Responses

Consistency within Survey

Subjects' responses to several pairs or triples of questions were compared to establish how consistently individuals displayed particular conceptual orientations. Questions chosen for this comparison contained at least one response that strongly reflected a particular conception, while other responses effectively precluded that conception. For example, question 6 response (a) strongly associates energy with people, but no other responses for question 6 do so. Similarly, in question 8, only response (a) displays this animate orientation.

6a (lifting book)	energy change is biggest when the book is lifted by a person
8a (submerged ball)	there is energy only where the person is forcing the ball to stay underwater

In five such cases, the number of students actually choosing responses which expressed the same conception was tallied and compared to the number that would be expected by chance (Table 21). The results, however, must be interpreted with great caution, for several reasons.

1. The number of subjects is so low that the apparent presence or lack of consistent responses might itself be a chance occurrence.

2. A given conceptual orientation expresses a preferred tendency to interpret situations in a certain way. It is the basis for judgement, not the judgement itself, so particular features of any particular situation may override a general preference.

Table 21. Consistency of Survey Responses

Conception	Item	Single Responses f	Single Responses P	Multiple responses* f	Multiple responses* P (observed)	Multiple responses* P ** (chance)
Human or animate	4a	20 of 84	0.2381	20 of 80	0.24	0.24 ***
	6a	35 of 80	0.4375			
	8a	24 of 80	0.3000			
Not human or motion	6c	17 of 51	0.3333	5 of 84	0.059	0.145
	8d	35 of 80	0.4375			
Depository	9d	27 of 81	0.3333	13 of 80	0.16	0.15
	10 a or c	37 of 80	0.4625			
Flow-transfer	7c	7 of 75	0.0933	1 of 75	0.093	0.035
	9 b or c	30 of 81	0.3704			
Transformation	4c	41 of 84	0.4881	19 of 75	0.25	0.31
	7d	47 of 75	0.6267			
Conservation	5e	3 of 83	0.0361	3 of 80	0.0375	0.007
	10 e	16 of 80	0.2000			

* At least two of the responses exemplifying this conception were chosen.
** Calculated as P (A and B), assuming responses are chosen independently.
*** Calculated as P [(A and B and not C) ... or (A and B and C)].

Thus, an individual's conceptual orientation is more likely to be uncovered through discussion and explanation of responses, rather than inferred from a small number of objective test responses. In this respect, interview and survey methodologies are certainly not equivalent, at least on the scale of this study. Larger-scale surveys designed to permit factor analysis might reveal an underlying structure in responses. This, however, would still require interpretation, which would presumably be facilitated by probing individual's responses, presumably in an interview setting.

Bearing in mind the cautions discussed above, the data suggest a difference in the consistency with which scientific and lifeworld conceptions were expressed, especially by high school students. The small number of students who expressed a conservation orientation did so in more that one situation. It is tempting to speculate that once this key aspect of a scientific conception of energy has been adopted, it tends to displace the lifeworld conceptions with which it competes.

Consistency between Survey and Interview

Seven of the 8 interview subjects also completed survey questionnaires. Their responses on parallel multiple-choice items (4, 5, and 8) were compared (Table 22). A substantial degree of consistency was shown. All subjects proposed identical answers to at least 1 of the items, and 4 of the subjects did so for all 3 items.

Table 22. Consistency between Interview and Survey

Subject	Survey No.	Item Responses (Survey|Interview)						Agreement
		4		5		8		
1	77	d	d	e	e	d	d	3 of 3
3	69	c	c*	c	c	b	a	2 of 3
4	72	c	c*	b	a	d	?	1 of 2
5	41	c	c*	c	c	c	?	2 of 2
6	53	b	b*	c	a	a	b	1 of 3
7	25	c	c*	c	c	d	c*	3 of 3
8	7	c	c*	a	a	d	c*	3 of 3

* Subject expressed some agreement with other responses during interview.
? Interview terminated before this point.

This result is limited primarily by the small number of subjects and items. Also, the questionnaire items were worded in the light of interview results, so there is less-than-perfect parallelism in response wording. Several of the interview alternatives were not mutually exclusive, so in extended conversation, subjects often found reason to give partial support to several answers. This was especially true for item 4.

Nevertheless, if the interview responses are taken as criterion, their observed agreement with the survey responses suggests a degree of concurrent validity for the survey. This does not contradict Treagust's (1988) claim that multiple-choice instruments offer a valid alternative to the traditional interview for revealing alternative conception. The small number of subjects prevents any stronger conclusion.

Consistency within Interviews: Student Profiles

As the conversation with each subject progressed, it often took on a distinct "flavour." The interviewer began anticipating particular features of the replies with some success. Study of the interview transcripts and survey questionnaires conveyed a similar sense of underlying consistency concerning those aspects of the situation which the subject attended to (or neglected) and the style of analysis applied to them.

The construct of conceptual orientation attempts to capture this structure by postulating a small number of favoured stances from which individuals perceive, describe and analyze any aspect of the physical world. A final aspect of this study, then, was an attempt to enter into each interview subject's orientation to energy, largely on an intuitive basis, in order to identify and describe the distinctive flavour of each individual's responses.

To support this effort, subjects' descriptions and explanations were examined for the presence or absence of words, phrases or complete statements characteristic of previously described conceptual frameworks (Table 23). Evidence suggesting a given framework was tallied only once for each item, even if it was expressed several times or in different ways. Ambiguous responses were tallied under all appropriate frameworks. Recognizing that particular words and phrases were used in various senses and were occasionally introduced by the interviewer, context was considered in the analysis. The resulting data is suggestive, but not truly objective.

Table 23. Conceptions Suggested during Interviews - by Subject

Conception	Subject								Total
	1	2	3	4	5	6	7	8	
Associations									
1.1 human activity......			3		1		2	2	8
1.2 motion		2	7	3	7	7	6	4	36
1.3 useful activities		2						3	5
1;4 undifferentiated ...		2	3	3			8	6	22
Nature									
2.1 energized state			3	2	2		2	2	11
2.2 substantive	1	2	3	5	3	6	3	7	30
What happens									
3,1 depository/used up	1	2	5	5	3	7	3	5	31
3.2 circulated	1	1	1	1	1	4	6	2	17
3,3 dormant/triggered		2	1	6	2	1		2	14
3.4 by-product					1	2	1	3	7
Scientific aspects									
4.1 abstract quantity	1	2							3
4,2 transferred	3	4	1	2		4	4	2	20
4.3 convertible forms	7	8	4	1		6			26
4.4 conserved	4								4
4,5 degraded	1	1	1	1					4
4.6 husbanded									0

An attempt was then made to construct a coherent descriptive profile of each subjects' approach towards those aspects of energy raised in the interview. This proved possible, although difficult. The results (presented below) are taken as evidence in favour of discernable consistencies in each student's conceptual orientation. They thus provide internal evidence of the construct validity of the interview and survey.

The profiles may also be dismissed as attesting to nothing more than the inventiveness of the researcher. Which judgement is more correct will only become apparent, according to Johansson, Marton, and Swensson (1985), if the orientations used herein prove to have descriptive power when applied by other researchers to other subjects.

Subject 1. In one form or another, this subject identified energy in 8 of the 10 interview situations. The total amount of energy in a system was always considered to be constant. Instead of being used up, therefore, energy was described as being transferred from one part of a system to another, or converted from one form to another. Thus, most elements of a scientific concept of energy were present in her analysis.

However, the concept of energy degradation was not conspicuous in her descriptions. Also, she appeared to rely on known examples of closed mechanical systems. When describing open biotic systems, she postulated a type of biological potential energy rather than tracing energy inputs. Similarly, although she recognized heat as a form of energy, she did not identify it as a major output of biological systems.

<u>Subject 2.</u> Some form of energy was identified in 8 of 10 situations. Energy in non-biotic systems was seen as being transformed, often to heat, and transferred from one part of a system to another. However, the amount of energy was described as varying, depending on the degree of activity, force or pressure present. Similarly, animate creatures were described as having energy only when they were active. Their energy was considered to be used up rather than transformed or transferred.

Electrical energy was described in quite different terms. It was thought to be concentrated in a battery in two forms, which would move through a closed circuit but stay dormant until they met. They would then react and be transformed into heat and light energy.

<u>Subject 3</u>. In all but one case, energy was associated only with motion or activity of animate creatures. Electricity was the exception: an open electrical circuit was considered to have energy concentrated in the battery. Although this subject generally used vocabulary appropriate to a substance, energy was also described as "weakening" and "being exerted", terms which evoke a less material picture.

Different forms of energy were named, but the possibility of change from one form to another was only recognized in one situation. Similarly there was only one mention of energy transfer. However, the amount of energy was not described as constant. Instead, it was said to be used up by activity.

<u>Subject 4</u>. This subject's interview was cut short, but in 6 of 8 situations, energy was described as a possibility ("potential"), suddenly triggered into existence as actual ("kinetic") energy. The latter was seen as able to be stored and then used up by

causing motion, or active resistance to motion. Apart from this unorthodox use of the terms "potential" and "kinetic", there was only one reference to different forms of energy.

In static situations such as the car on the hoist, energy was assigned to whatever active or potentially active agent was being resisted (gravity) as well as to the resisting object (the hoist). The object being acted upon (the car) was not seen as having energy until resistance weakened. Then, energy suddenly appeared in it. Only in situations involving heat and electricity was energy transfer identified.

Subject 5. This subject did not express any aspects of the scientific conception of energy. Opportunities to mention energy transfer, transformation and conservation were not seized. Energy was seen as present in situations involving activity or active resistance to motion. However, no consistent image emerged: energy was variously spoken of as a state and as a substance that is stored and expended, circulated, triggered, or created from something else. In conversation, one image of energy tended to be proposed, considered briefly, and then abandoned (not rejected) in favour of other, possibly opposing ideas. Non-verbally and by intonation, the subject conveyed little impression of commitment to any of her proposals. Instead, there was a consistent tendency to flirt with ideas, flitting lightly from one to another, with little detailed examination or comparison.

Subject 6. Energy is associated with motion or activity. It takes different forms and can change from one form to another. Living things produce (or activate) it from food when needed for some activity or task. Although this subject usually described energy as being used up, it was sometimes said to be transferred to different parts of a system, or just released into the air. In electrical circuits, energy circulates (but energy is not electricity). In any event, the quantity of energy varies over time; suggestions that it might be conserved were categorically rejected.

Subject 7. Energy is associated with motion, but also in a quite intricate fashion with heat. Motion is said to involve a force or pressure of energy, which pulls or pushes an object. The amount of energy varies with the object's speed. The energy originates with outside sources like the air or gravity, but is transferred into the object "on demand", when it moves. The energy is described as moving or circulating through the object along with heat (and cold). Heat is seen variously as a carrier, a product, and (in people) as a source of energy. Human energy is also produced when needed from food, and circulates out of the body along with sweat.

Electrical circuits are viewed differently. Energy is stored in a battery and moves through the circuit wires without a carrier. In a light bulb, however, some substantive part of the energy is lost and circulated into the air along with heat and light.

Apart from being transferable, this view of energy has none of the characteristics of the scientific conception. Energy is not recognized to have different forms, is not conserved, and does not undergo any process of degradation.

Subject 8. Energy is associated with the performance of tasks. Objects like tables don't do anything active, so they don't need or have energy unless (and while) they are moved or heated up. Energy is then created in them from the gravity, force or heat they receive, as a byproduct of being acted upon.

Machines and people, by contrast, can do things, and they use energy in the process. Energy moves through machines as a type of fuel, building up or being picked up from the surroundings before the task begins, and being burned off or carried by heat into the surroundings as a sort of exhaust.

Similarly, people become energetic when they perform tasks. Their energy is gathered from the air or created from food as needed, but is just lost when they become inactive.

In all cases, energy is associated with, but not identical to, heat and motion. Energy serves as a carrier for heat, and is active or powerful to the extent that it moves and is charged with heat. Energy is described in very physical, substantial terms: it can be compressed and in electrical circuits it hits various components, losing part of its substance in the process.

Energy (carrying heat) can be transferred, but only when objects touch. No other aspects of the scientific energy concept were evidenced during the interview.

Chapter 5

Summary and Conclusions

Summary of the Study

A long tradition of research has documented how children appear to think about the natural world quite differently than scientists. Objectives, style of thought, and actual concepts of " children's science" appear to be distinctive, persistent, and resistant to direct instruction. Many research perspectives and methods have been applied to this problem, largely by investigators outside of North America. Interpretive research based on varieties of clinical interviews has been favoured. The theoretical notions of misconceptions, alternative frameworks, and conceptual orientation have been developed to structure the research.

Conceptual change theories and constructivist pedagogy propose that expression and acknowledgement of alternative conceptions is an essential task of school science instruction. Observational studies show that these activities are rare in actual school science teaching. Thus, gathering and organizing knowledge of alternative conceptual orientations and incorporating it into school science programs is a significant challenge on both theoretical and practical grounds.

The present study investigated alternative conceptions of energy in a previously unstudied population: Alberta secondary school students. It addressed five research questions:

1. Would misconceptions and alternative conceptual orientations reported in the literature also be evident in this population?

2. Would interviews and written surveys result in similar patterns of responses?

3. Would there be noticeable differences in responses between grade 9 students and grade 11 students?

4. Would the proportion of students utilizing a scientific orientation vary between classes in different disciplines?

5. Would students consistently utilize a given conceptual orientation?

A three phase methodology adapted from Treagust (1988) was used in a modified form for the study. Surveys of curriculum statements and of previous research were used as the basis for constructing ten pairs of questions about energy. Eight semi-structured interviews were conducted around one question of each pair, using interview-about-instances drawings and actual models. Audiotapes of interviews were transcribed and used to refine the second question of each pair for use on a survey instrument. Both open-ended questions and multiple choice items with written justification of answers were included. The survey was completed by 84 students, including seven of the eight interview subjects.

Interview transcripts and survey responses were examined for indications of alternative conceptual orientations. Multiple-choice response patterns for each class were compiled and statistically analyzed for significant differences. Responses to survey questions expressing the same conception of energy were compared. For interview subjects, responses to selected item pairs (interview and survey) were examined to determine whether similar conceptions were revealed by the two methodologies.

An unexpectedly large number of survey respondents, but not interviewees, spontaneously used energy concepts to describe a familiar situation. Participants in the study expressed a variety of alternative conceptions about energy similar to that found in previous studies. Scientific terms such as kinetic and potential energy were used to label distinctly non-scientific conceptions. Poor differentiation of energy from ideas of heat, force, and pressure was also evident.

The construct of conceptual orientation was found to be applicable to analysis and description of interview conversations and written responses on the survey. Interview responses exhibited sufficient consistency to enable the construction of individual profiles of conceptual orientation. Furthermore, interview subjects appeared to respond in a relatively consistent manner on parallel interview and survey questions.

Response patterns for 3 of 8 survey questions showed statistically significant differences between classes and grade levels ($p < 0.05$, chi square). A trend towards more scientific responses by grade 11 students, compared to grade 9 subjects, was noted for many questions. There was some indication that students who most strongly expressed aspects of a scientific conception did so more consistently than students who expressed other conceptions.

Discussion of Findings

Research Question 1

Will misconceptions and alternative conceptual orientations reported in the literature also be evident in interviews and written surveys of Alberta students?

Conclusion

Using sentences as the unit of analysis, interview responses and written justifications of surveys were found to resemble many of the alternative frameworks described by Stead (1980), Watts (1983a) and subsequent researchers. Subjects' acceptance of multiple choice responses which exemplify specific conceptions further supports this finding. Several other alternative conceptions were not precluded by the data, but no unambiguous exemplars of them were obtained.

This result was anticipated, although no parallel studies have been reported for North American students. Subjects in the present study were expected to have lifeworld and school experiences similar to those of students in other English-speaking, technologically advanced countries. Research conducted in the United Kingdom, New Zealand, West Germany and the Philippines has revealed similar alternative conceptions between populations with much greater linguistic and cultural diversity.

Discussion

Evidence of particular alternative conceptions has been presented in the discussion of interview and survey findings. It is summarized thematically below, arranged according to the three major aspects of energy identified in Chapter 4: (1) situations energy is associated with, (2) the nature of energy, and (3) what happens to energy over time. Findings which bear directly upon the scientific concept of energy are discussed later, with research question 4.

1.1 Energy is associated with living things. No non-human living creatures were portrayed in the interviews or survey, so no direct evidence was obtained about the prevalence of this conception, which was described in detail by Solomon (1983b) and Stead (1980).

1.2 Energy is associated with human beings. For some subjects, the presence or activity of human beings was the prime criterion in deciding that a situation involved energy. The absence of human beings, or other living creatures, indicated an absence of energy.

> How can a fence have energy like human beings do? 53: S2 9

> A machine has no life, so it should need no energy. It runs on gas or electricity. No energy is needed for the machine. 36: S6 33

> Humans would put most of their energy into their arm so they could hold the book. A robot arm doesn't transfer any energy because he's made out of metal. 54: S6 9, 35

> The person is using all the energy to push the box up [the hill] because even if the box had energy it can not push itself up. 55: S9 24

Three survey responses which directly associated energy with human beings were chosen by about one quarter of the subjects.

Item	Responses	Description
4 response a	20 of 84	Energy changes of a moving bicycle occur when the cyclist stops pedalling, rather than when the bike slows or stops.
6 response a	24 of 80	Energy is involved in lifting a book only when a person does the lifting, not if a machine is used.
8 response a	24 of 80	A submerged ping-pong ball has energy when a person holds it underwater but not after it is released.

These finding parallel those originally reported by Solomon (1983b) and Stead (1980). They suggest a sort of vitalism which equates energy with a life-force or quality possessed only by animate creatures. Machines may be powerful, but their metal parts and fuels are only a substitute for the self-directed focussing of energies by which people accomplish tasks.

1.3 Energy is associated with movement. In this view, a lack of motion can imply no energy. For example, there is no energy associated with a rock balanced on a fencepost because,

> ... it's just sitting there on the fencepost. It's not moving or anything. 56: S2 2,7,12, 17, 21, 28, 48
>
> No motion, no energy! 57: S8 69, 81

Lack of motion can also suggest the presence of energy which is opposing an apparently natural motion. When a ping-pong ball is held underwater,

> the person is holding back the energy of the ping-pong ball, and while pushing against the ball's energy he is using up energy. 58: S8 64
>
> It takes more energy to hold it underwater because the ball wants to float. 59: S8 19, 20, 29, 62

Moving objects, on the other hand, are seen as having (or needing, or creating) energy.

> As the pendulum moves faster, the more energy is created. 60: S10 19
>
> [A pendulum] wouldn't need any energy to be stuck to the wall, but it would need some to break through all the molecules in the air. 61: S10 34
>
> If [a bicycle] was coasting there was a loss of speed and a loss of energy. When the bike is completely stopped ... there now is no motion and ultimately no energy. 62: S4 33, 62, 80

Four survey responses were compatible with the association of energy with motion and gathered considerable support.

Item	Responses	Description
4 response b	20 of 84	There are energy changes as a bicycle slows down and stops.
5 response c	58 of 85	An exploding balloon has most energy as it breaks into moving fragments.
8 response b	15 of 80	A submerged ping-pong ball has energy only when it is rising to the surface.
10 response d	17 of 80	The energy of a pendulum varies with its speed.

A common conceptual link between motion and energy was reported by Brook and Driver (1984), Solomon (1983b) and Watts (1983a). A number of comments reported earlier in the present study further illustrate this conception.

1. Motion implies energy: quotations 5 (page 99), 14 (page 104), 26 (page 119) and 52 (page 139).

2. Lack of motion implies no energy: quotations 15 (page 106), 23 (page 111) and 24 (page 118).

3. Energy is needed to prevent natural movement: quotations 2 (page 97), 21 (page 109) and 25 (page 119).

<u>1.4 Energy is associated with useful work</u>. Getting something done can be seen as a sufficient indication of the presence of energy. Whether the task is performed by a person or by a machine seems, in this view, to be unimportant.

> You have to use energy to do anything, no matter how big or small the task is ... 63: S9 23, 44

A solar cell's energy is released by sunlight because,

> You need some light for the light bulb, so that is an easy way [to get it]. 64: S7 43

There is energy involved in pushing a box up a hill because,

> If there was no energy the box would still be at the bottom of the hill. 65: S9 28, 73

A balloon has the most energy when it explodes, because it

> ... is doing the most when it explodes and gives a great deal of energy to do that. 66: S5 26

An extreme version of this conception described by Watts (1983a) would restrict energy to tasks that are of direct benefit to human beings. Thus, energy becomes a sort of technical aid to comfortable living. This view was clearly expressed by a subject who saw a balloon as having more energy just after its string is lit, because

> ... the fire is a means of warmth to the people around it. There is no energy when it blows up because it is of no use except to scare people, which causes them to jump and use energy of their own. 32: S5 4

Other illustrations of a conceptual link between energy and task performance include quotations 15 (page 106) and 22 (page 110). Two survey responses also were compatible with this conception.

Item	Responses	Description
9 response a	20 of 81	Energy is produced in a person's body so that a box can be pushed up a hill.
10 response b	12 of 80	A pendulum's energy increases as it gathers energy to swing.

It seems clear that some subjects are inclined to associate energy more strongly with task performance than with speed, presence of humans or animate objects, or similar particular features of a situation. Apart from quotation 32, above, however, there was no explicit demand that the task be useful to human beings. Inclusion of items which directly contrast useful and trivial tasks might clarify this point.

The way in which subjects actually relate energy and task performance is also uncertain. It is not clear from the written responses whether energy is seen as a necessary prerequisite of action, whether it is an accompanying feature, appearing "on demand" when something is being done, or whether, as Watts (1983a) suggests, energy is equated with the action. Again, these possibilities could be directly contrasted in a revised survey instrument.

1.5 Energy is confused with other physical quantities. Energy was sometimes described in direct sensory terms which seem more appropriate to other physical quantities. A bicycle coasts to a stop, for example, because

> ... the pressure of the energy pushes the bike to a stop. 67: S4 13
>
> ... there is no energy pushing you to go. 68: S4 73

Energy was also linked in an overly specific, and therefore scientifically incorrect, manner to other quantities.

> no force = no work done = no energy 69: S4 81, 83

The most common confusion in the interview responses appeared to be an overly differentiated view of energy. Rather than an all-embracing concept applicable to any physical situation, energy appeared to be regarded as just one of many physical quantities, applicable in some situations but not in others. When a rock is balanced on a fencepost,

> There is no energy. However, there is gravity involved. 70: S1 29, 5, 8, 19

As a pendulum swings,

> ... it is using no energy at all. It is using the force of gravity. 71: S10 4, 17

When a person releases a ping-pong ball that is being held underwater,

> The only reason the ball rises is because of density, not energy. 72: S8 17
>
> ... there is only buoyancy, and I'm not sure if that is considered energy. 73: S8 32

Energy was also seen as something other quantities could create or into which they could be transformed. As a balloon explodes, for example,

> all the forces inside are let out and converted into energy. 74: S5 81

A solar cell can light a flashlight bulb because

> Sun gives off heat and the heat causes energy ... 75: S7 20

Such comments suggest the inverse of a scientific conception. Rather than a general characteristic (energy) which can appear in different forms, they describe energy itself as formed from other, more primary physical quantities. As in quotation 75 (above), heat was strongly associated with energy by several interview subjects, either as something produced by energy, or as an ingredient that makes energy, energetic.

> The hand is using energy from the body to hold [the grip strengthener). Um ... the little gripper thing has energy 'cause it could pop open. There's heat because you're holding it so tightly, your hand is getting hot and that. (So is there anything happening to the energy right now?) It's changing to heat 76: I7 1 (140-142)
>
> You're just using up your energy to squeeze the things together.... And, it takes energy to keep them squeezed .... (What happens to the energy?) ... It's ... I don't know, I think it's just being, maybe switched to heat, or ... and then you can just sort of feel it. Your hand gets sweaty after a while of holding something, And it's just sort of released into the air. 77: I7 6 (145-152)
>
> [In an electric circuit] ... the energy and stuff come out of the battery and go into the light bulb and turn it on. (In the light bulb, what's happening to it?) I think it's kind of getting used up, like... I think the heat goes out of the energy. And causes ... I don't know ... a spark or something. And the light comes on and then it has to glow. (What happens when the battery goes dead?) ... Well, maybe there's like, no heat left. Like you can't put anything else into the energy, so it stops. 78: I7 8 (140-156)

None of the multiple choice survey responses directly contrasted energy and related concepts. However, a number of other examples of lack of differentiation between energy and other physical quantities appeared in the written responses and have been cited earlier. Those related to heat include quotations 7 (page 100), 8 (page 101), and 16 (page 106). Confusion with electricity is evident in quotation 18 (page 107), and with force in quotations 21 (page 109), 44 (page 133) and 46 (page 135). Quotation 42 (page 132) confuses energy with density, and quotation 43 (page 132) with buoyancy.

Similar confusions have been noted by other researchers, including the CLISP group (Approaches to teaching energy, 1987), Brook and Driver (1984), Duit (1981), and Watts and Gilbert (1982). It is possible that they reflect nothing more than the linguistic imprecision common to everyday conversation. In an interview setting, however, subjects are given every opportunity to clarify their statements. Their inability to make appropriate distinctions between energy and related concepts seems likely to indicate imprecision in the concepts themselves, rather than in the labels used for them.

2.1 Energy is a state of vitality. An everyday sense of the term "energy" associates it with health, strength, and well-being (Solomon, 1983b).

> The box can be pushed quicker if you use strength and energy. 79: S10 38
>
> The person is alive. We have lots of energy, and when we use a little, lots has to be made. 80: S6 44

This nuance was also evident when subjects in the present study contrasted the human ability to make an effort with the way in which machines work.

> When a person lifts a book there is an energy change because they are using their strength, but a machine is just using power. 81: S6 14, 1, 3, 12, 15, 20, 21

> Machines are much stronger than humans. Therefore [they] can lift with little energy. 82: S6 38, 7, 39, 64, 68)

Quotations 35 (page 128) and 38 (page 128) further illustrate this view.

The descriptive terms used for energy were sometimes appropriate to a state of being, rather than a "thing". Examples were few, but striking.

> ... all his energy starts to relax when he's at the top of the hill. 83: S9 9

> (Is anything happening to his energy?) Yeah, it's getting tired. 17: I6 5 (157-157)

More commonly, descriptions were ambiguous, equally applicable to energy seen as a state of being or as a more substantial entity. Moving a box

> ... takes a lot out of a person, you know. 84: S9 26

> The person needs energy to push and after he's done pushing he's lost his energy. 85: S9 37)

No multiple choice responses directly contrasted a view of energy as a vital state with the more substantive view discussed next. The explanations quoted above merely admit the possibility of a vital-state concept of energy in the sample population, at least to some limited extent. The more limited claim of a widespread association between energy and human (or animate) agents or activities, discussed earlier in this chapter (sections 1.2 and 1.4) appears better justified than inferences about the nature of energy as a substance or vital state.

2.2 Energy is a substantive causal agent. Previous research has suggested that talk about energy is usually couched in concrete, substantial terms, suggesting that it is regarded as a sort of generalized fuel for change (Gilbert & Pope, cited in Brook, 1986; Watts, 1983a). Associations of energy with motion and accomplishing tasks, illustrated in previous sections, appear to support the fuel aspect of this interpretation. One subject stated the matter quite explicitly:

> ... no matter what you do, you're using energy. 86: S8 34)

Various properties of material substances are commonly ascribed to the energy-fuel: ability to be stored, circulated, used up, transferred from place to place, and so forth. The physicist's abstract conception of a convenient "energy-number" calculable for any ph.:ical system is seldom expressed. This tendency was also evident in the present study, especially in interviews. Several examples have already been cited. When a grip strengthener is released, for example,

> I think some of the energy is letting loose // as your letting go, it's not held as tightly together. And the energy is kind of moving around more freely, and not as packed together as it was. So it's looser and has more places to go. So it's kind of ... moving out.
>
> (Where does it go?) Well now, it could be moving. 'Cause when you're packing it tightly together, it's all kind of ... bunched up, and it kind of just ... goes back into the handles more, and up into the ring. Or else, it could be escaping and stuff. 20: J8 8 (172, 185-186)

Other descriptions, however, are framed in less physical terms. They could apply to an energized state as well as to an energy substance.

> ... as you're winding [a toy truck] you'd be putting a little bit more energy in it, so it moves. And then when it slows down I think it's kind of losing its energy // it just kind of ... goes away. (Does it just vanish?) I think it just kind of mixes in with the air. And you can't tell it's there, but it is there. 12: J4 8 (084-095)

It is not clear whether such comments reflect any strong commitment to a substantive conception of energy. Everyday discourse, at least in English, commonly lends a concrete, quantifiable air to the insubstantial. We say there is "not enough light to read by" at least as easily as we describe a room as "dimly lit." A person is said at one time to be "displaying a great deal of courage" and at another to be "very courageous." Scientific talk can be similarly inclined to the concrete. We say a stretched spring "has a lot of potential energy", rather than describing it as "potentially highly energetic."

When reflecting upon his concept of energy, of course, a philosophical physicist may find graceful words to express its insubstantial character (see Feynman, cited in Approaches to teaching energy, 1987, p. 4). Subjects in this (and similar) studies are unlikely to have considered the matter in such depth. Their comments might be interpreted as reflecting an undifferentiated conception expressed with the ambiguity of everyday speech. To go further and postulate a widely held alternative conception of energy as substantive seems unwarranted, at least on the basis of the present study's findings.

The concrete tone of everyday speech also presents a methodological problem. In the present study it proved extremely difficult to formulate concise descriptions and carry on comfortable conversations in terms which would be neutral in their presentation of energy as a state or as a substance. It is possible that subjects were predisposed towards responses with a substantive tone even by such almost unavoidable phrases as "getting" or "having the most" energy. Alternative formulations such as "becoming energetic" or "in the most energetic state" are sufficiently pedantic to impede conversation, and sufficiently unusual to act as strong cues for a similar style of answer. Similarly, no satisfactory multiple choice responses could be phrased in a manner which directly contrasted the two views without drawing undue attention to one or the other.

As a result of these limitations of design and interpretation, the present study is not considered to have provided clear evidence for or against a widespread substantive conception of energy.

3.1 Energy is stored in some objects, needed and used by others. Previous researchers have reported many examples of this "depository" conception (Gilbert & Pope, cited in Brook, 1986; Watts, 1983a). As a result, it was not surprising to encounter statements reflecting all three of its main characteristics during the present study. However, each aspect had unexpected shadings, and will therefore be discussed separately.

Some objects were described as reservoirs, storing energy by virtue of their nature or particular situation. In a balloon,

> ... before the string is lit, it is storing its energy and not using it. 87: S5 7, 49, 60)

If a person holds a ping-pong ball underwater,

> ... the ball is absorbing energy until it is released. 88: S8 60
>
> The person is storing potential energy in the ball as the person holds it underwater. 89: S8 49

As previously noted, some subjects used the term "potential" energy to indicate the capacity of such energy reservoirs (page 95). The reservoirs were viewed as lacking energy until some necessity triggered its sudden appearance.

Objects and people were frequently described as needing energy to do things or to be in anything but some presumed natural state. Energy may not be considered necessary for a stone to lie on the ground, for example, but when it is placed on a fencepost the situation changes.

> You need energy to hold up everything: the earth to hold up the post, the post to hold up the rock. 90: S2 15, 26, 40, 41, 44, 51, 55, 65)

A pendulum stuck to a wall

> ... needs its energy to break free, then swing, but as it starts to climb it needs its energy again. 91: S10 9

An inflated balloon

> ... needs lots of energy to pop // in little shreds. 92: S5 37, 51, 61

> It needs energy to explode, and that is when it has the most. 93: S5 33

Other descriptions of a need for energy are found in quotations 6 (page 100), 11 (page 102), 14 (page 104), 15 (page 106), 21 (page 109), 29 (page 123) and 50 (page 138).

The somewhat mysterious appearance of energy in times of need, apparent in quotation 92 (above), also featured in other responses. Possibly it represents an extension of the human experience of gathering or focussing energy to perform a task like climbing stairs.

> (Where does this extra energy come from?) Um ... I guess your mind. Like, you see the stairs coming so you kind of know that you're going to have to use energy to walk up the stairs. So I guess you just, you sort of tell yourself that you've got to walk up the stairs and kind of get some energy. 22: I10 6 (173-174)

A third element of the depository view is that objects use energy up in the performance of a task.

> When the [bicycle] rider stops pedalling, there is no more energy being given to the wheels. Therefore, the wheels use up the energy stored in its speed and eventually stop. 94: S4 59, 65

> The pendulum has energy to swing down, uses it up going up, and gathers more going down. 95: S10 36)

Two survey responses also embodied descriptions of energy as diminishing or being used up during changes. Their appeal gives further evidence of the widespread tendency to adopt this aspect of a depository orientation towards energy.

Item	Responses	Description
9 response d	27 of 81	Energy is being used up pushing a box.
10 response a	16 of 80	A pendulum's energy goes down as it swings

The image of a limited supply of energy-fuel which diminishes as events occur parallels to some extent the thermodynamic concept of free energy. As such, this aspect of the depository framework has been suggested as a suitable starting point or anchoring conception from which to develop the broader scientific view of energy (Clement, Brown, & Zietsman, 1989; Ross, 1988).

3.2 Energy circulates like a fluid. Previous research has shown that electrical and hydraulic systems, as well as instances of heat transfer, are often described according to this "flow-transfer" conception (Duit, 1981; Watts, 1983a). Further examples of this orientation were evident in the present study. In an electric circuit, energy

> ... is in the battery. // It's like they're sticking to something inside the battery. And then once the switch is on it ... just sort of has an opening and drains through the wire ... 18: I7 6 (123-126)

When a solar-powered flashlight operates,

> Energy produced in the solar cells is carried to the bulb through wires, charging the bulb, therefore causing it to light up. 96: S7 0

Clearly, a flow-transfer conception does not preclude notions of energy accumulations. It also accommodates the notion of certain objects or tasks needing or using energy. However, instead of being used up like a fuel, energy in this model is dissipated, or loses its potency. It moves in and out of objects without ceasing to exist. When a wind-up toy is operated, for example,

> I think when you're winding it up, it's moving the stuff inside. And it's picking up more energy. (From where?) Outside, like ... from the air particles and everything.
>
> And then when it slows down I think it's kind of losing its energy // it just kind of ... goes away. (Does it vanish?) I think it just kind of mixes in with the air. And you can't tell it's there, but it is there. 12: 14 8 (095-098, 084-095)

Because responses displaying a flow-transfer conception describe energy as persistent rather than consumable, this orientation may provide a useful stance from which to approach the idea of conservation of energy.

Two survey responses explicitly contrasted a view of energy flow and transfer with descriptions of energy being used up. Support for them is considered to be further evidence of a flow-transfer conception.

Item	Responses	Description
7 response c	7 of 75	A solar cell charges electricity with energy, which is then carried through the circuit.
9 response b	18 of 81	Energy is transferred from a worker to a box being pushed uphill.

<u>3.3 Energy is dormant until triggered</u>. Energy is sometimes described as a sort of possibility associated with objects or situations (Watts, 1983a). It is not really present, at least not in an active, full sense, until the proper conditions are established. At that time, this dormant ingredient or "potential" is released or triggered into action. Occasional suggestions of such a conception, or aspects of it, were gathered in the

present study. A few subjects spoke of energy being released without any suggestion that it had previously been stored up. For example, in the solar powered flashlight,

> Sunlight releases rays that hit the solar cell and it releases energy and make[s] the bulb light up. 97: S7 7, 10, 14, 23, 51, 54

A balloon has most energy as it explodes because

> ... that is when the energy is released from the balloon. 98: S5 17, 31, 53, 54, 65, 83

Two survey responses described situations in which energy release was triggered, and are thus considered compatible with this conception.

Item	Responses	Description
7 response a	13 of 75	Sunlight releases the energy of a solar cell.
7 response b	6 of 75	Electricity releases the energy of a light bulb.

Watts (1983a) provides an illustration which likens an object's dormant energy to a seed, able to flourish and mature given the proper conditions. A similar flavour pervades several other descriptions of the bursting balloon.

> It has energy when it is blown up, but has way more as it explodes. 99: S5 46

> As it explodes the air in the balloon is suddenly given a radical boost of energy ... 100: S5 73

> All the balloon particles fly outward. So does the energy from inside, and the energy is pushed so hard and fast more energy is released, because of the flame hitting the balloon. 101: S5 23

As previously noted in the discussion of interview findings, the term "potential" energy was occasionally used to indicate the energy-capacity of some object or situation (page 95). The energy was not described as stored or actually present. Rather, it was a possibility, actualized when some event or necessity triggered its sudden appearance. This distinctly non-scientific usage, identified by Stead (1980), appears quite parallel to the dormant ingredient conception. When a marble is held high on a track,

> It [has] potential energy. And once it rolls down it would go into kinetic and then that will turn into heat energy. (In your mind,what do you mean by potential energy?) It has the ability to do work ... to release heat ... if it is released. (Has it got that ability right now // as I'm holding it?) No. (So when I release it, what happens?) Then it has energy // when it's released it's got kinetic energy " It changes into kinetic. 1: I0 2 (012-028)

In the exchange quoted above, considerable probing was required before a clear statement of the conception emerged. Had survey responses that hint of energy release without energy storage been subject to equally intense probes, perhaps more definitive statements would have resulted. However, the existing data is viewed as providing only oblique support for the presence of a dormant ingredient conception in the sample population.

3.4 Energy is a byproduct of activities. Previous studies have suggested that energy is sometimes described as a non-essential accompaniment or result of activities, a sort of short-lived exhaust. (Stead, 1980; Watts, 1983a). Similarly, in the present study energy was frequently described as appearing or being created as activities occurred.

> When a biker stops pedalling the motions which caused the energy stop and the bike just coasts along and no energy is being produced any more. 102: S4 27, 2, 3, 16, 17, 19, 66, 68)

> All action or movement creates energy. 103: S4 16)

In an exploding balloon,

> All that heat and pressure builds up into energy and that is why it explodes. 104: S5 3, 41

> Because of the explosion the particles fly out in different directions, slamming into other particles, creating energy. 105: S5 2

When a person works to push a box uphill,

> The box being pushed by the human makes the person produce energy. 106: S9 30

When a pendulum swings,

> ... the speed of the object produces a lot of energy moving back and forth. 107: S10 25

> The most energy is when it's pushing the air out of the way to swing down, producing lots of energy. 108: S10 27

Other sources of energy have been mentioned in previous quotations: heat (quotations 16, page 106, and 39, page 130), light (quotation 41, page 130), mechanical collisions (quotation 34, page 126), and pushing an object (quotation 46, page 135).

These findings must be regarded cautiously. While they do not preclude the by-product conception, they do not clearly explain the role energy is considered to have once it has been produced. In particular, they admit the possibility that energy is being used as a global term for all the movement and change which comprise the action situation itself. The only survey item which probed this conception (7e) suggested that energy could be produced by a reaction between electrical currents. It gathered little support (2 of 75 responses). Thus, while the present study provides evidence of the possible existence of a byproduct conception in the sample population, it is not considered to definitely establish the presence of this conception.

<u>Research Question 2</u>

Will subjects show a similar pattern of responses to interviews and written surveys?

<u>Conclusion</u>

Subjects tended to choose similar responses on parallel interview and survey questions (Table 20). This is taken as limited support for Treagust's (1988) claim that carefully constructed multiple choice instruments offer a valid alternative to interviews for probing alternative conceptions in a classroom setting.

<u>Discussion</u>

This finding is a very limited byproduct of the investigation and must be regarded as suggestive, not definitive. As previously discussed, the multiple choice responses proposed for the interview items were exploratory and often not mutually exclusive (page 142). Several subjects found reason to support more than one response to a given question. Also, interview findings were used, as planned, to refine potential survey questions. For most questions, this reduced the original parallelism between the two sets of items and rendered direct comparison of results impossible. Finally, 2 of the subjects did not complete the entire interview schedule, and only 7 of the 8 interview subjects also completed surveys.

As a result of the small number of items and subjects which could be compared, no statistical validation of the apparent similarity of their interview and survey responses was warranted. Nevertheless, the indications of parallelism are intriguing.

The question certainly admits to further research using refined interview and survey schedules designed for the purpose.

Research Question 3

Will there be noticeable differences in responses between grade 9 subjects, who have not received a formal introduction to energy at secondary school level, and grade 11 subjects, who were introduced to the subject two years previously?

Conclusion

With three exceptions (questions 2, 5, and 9), survey responses showed no statistically significant difference in response patterns between classes at the different grade levels (Table 24). However, analysis of interview transcripts showed that the two grade 9 subjects accounted for only 6 of 57 references to aspects of the scientific concept of energy (Table 23, page 144).

Table 24. Survey Response Patterns - Significance by Class

Item	1	2	3	4	5	6	7	8	9	10
p	*	0.0041	0.4322	0.2643	0.008	**	0.1122	0.5077	0.0127	0.0641
Significant? $p < 0.05$	-	yes	no	no	yes	-	no	no	yes	no

* Open response question ** Two versions of question used, so no analysis attempted.

Discussion

The widespread presence of alternative conceptions among secondary students at different age levels was expected. Previous investigators have found non-scientific conceptions to be tenaciously maintained, even as scientific concepts are learned.

Results of the present study are compatible with the notion that scientific ideas may be segregated from more everyday notions, being held in reserve, so to speak, for situations in which their use is clearly indicated. Thus, students may display technical vocabulary in science class and choose correct answers on science tests, even while maintaining and applying quite different and even contradictory lifeworld notions outside of class (Osborne & Freyberg, 1985).

If this is the case, scientific ideas of energy would not likely be raised in conversation except by people who have been specifically introduced to them. They are sufficiently abstract and counter intuitive to preclude spontaneous discovery and expression by students such as the grade 9 subjects of the present study. Older students, having been introduced to scientific notions, might discuss them if they were raised in a school setting by a science teacher. (Both conditions were embodied in the present study.) The same students might not, however, have developed sufficient commitment to a scientific viewpoint for it to displace alternative conceptions when interpreting situations independently. In effect, the scientific conception could be known but not adopted, appearing in conversation when cued by the situation but not being reflected in more everyday, independent judgements.

Research Question 4.

Will the proportion of students utilizing a scientific orientation vary between classes?

Conclusion

In both interviews and surveys, grade 11 physics students produced the largest proportion of responses which exemplified scientific energy conceptions. This result is based partially on qualitative analysis of interview transcripts. In the survey, questions 2, 5 and 9 produced differences in response patterns between classes that reached statistical significance ($p < 0.05$). This result is based only on quantitative analysis of survey results, which must be regarded with considerable caution due to the small number of subjects and the leading and exploratory nature of some of the questions.

Discussion

Physics students are often regarded as more likely to be academically engaged and capable than general science students. They might, therefore, be expected to have adopted comparatively more of the reasoning patterns and scientific knowledge taught in school science courses. In fact, during the eight interviews, the 2 physics students made 31 of 57 references to aspects of a scientific conception of energy, while the general science students made only 10 such references, all by the same student (Table 23, page 144).

Table 10 (page 112) shows that in the seven survey questions for which a scientifically acceptable response could be clearly identified, physics students showed a greater preference than other subjects for that response in all but two cases. In only one case (question 4) was the most scientific response chosen by a greater proportion of general science than physics students. Question 4 involves changes in energy as a cyclist stops pedalling and coasts to a stop. A focus on motion of inanimate objects, which might be expected from physics students, leads to a response which neglects energy conversions involved in pedalling. Both general science and biology students were more successful than physics students in associating energy changes with this activity by a living organism. In one other case (question 9) physics and general science students showed an equal attraction for the most scientific response. As previously discussed, the wording of the most scientifically acceptable response was somewhat anthropomorphic, which may have made it appear less plausible (page 135).

During the data analysis, some insights were gained about subjects' reaction to each aspect of the scientific concept of energy. These interpretations are summarized briefly below.

4.1 Energy is an abstract quantity. Only the two physics students made any reference during the interviews to energy as a general characteristic of any physical situation (Table 23, page 144). According to the core curriculum, however, this idea should be stressed at junior high level for all students (Table 3, page 52). From a Piagetian viewpoint, one might speculate that junior high students are not generally capable of dealing with this degree of abstraction. Instead, the concept of energy may be subdivided into manageable instantiations.

> With the person holding the book, it is human energy, but when a machine lifts, it's energy produced by electricity or whatever the machine runs on ... 35: S6 27

Other subjects restricted energy to a particular type of situation: motion, for example, or accomplishing a task. Still others differentiated the concept until energy became just one of many roughly equivalent situational features which might trigger physical changes.

> The only reason the [submerged ping-pong] ball rises is because of density, not energy. 42: S8 17

The presentation of different forms of energy throughout elementary and junior high school may support this "divide and conquer" strategy. Students with limited ability to generalize across concrete examples may focus on the initially obvious difference between, for example, "heatenergy" and "lightenergy". The generalization intended by labelling them as different forms of energy may not be perceived or internalized.

4.2 Energy is transferred from place to place. This concept figured in all but one interview (Table 23, page 144). It was also used in justifications of survey responses. In a solar powered flashlight, for example,

> Light energy from the sun is stored within the solar panels and than transported to the bulb, lighting it up. 109: S7 58, 6, 9, 62

When cold lemonade sits in a hot room,

> The heat energy taken from the air is absorbed by the lemonade. This should continue to occur until an equilibrium is reached ... 110: S3 76, 75

Survey responses 9b and 9c spoke directly of energy "transfer" and "sharing", and were supported by 18 and 12 subjects (out of 81), respectively.

The idea of energy transfer appears to arise quite logically from a flow-transfer conception, which views energy as circulating through a system, perhaps losing potency, but not being consumed. Transfer is equally possible to visualize whether the object of the transfer is conceived in concrete terms or as a less substantial, but still mobile, quality. The relative accessibility of this aspect of a scientific conception of energy is thus not difficult to understand.

<u>**4.3 Energy occurs in many interconvertible forms**</u>. The notion of different forms of energy was suggested by 5 of the 6 grade 11 interview subjects. It also appeared in a number of explanations for survey responses.

> [A cyclist] has potential energy which he converts to kinetic energy. Then the kinetic energy is changed to heat energy and possible sound energy. 111: S4 42, 82
>
> [In a burning balloon] energy changes from potential to heat and then to kinetic and heat again for the explosion. There is no energy change, just transfer. 112: S5 76
>
> [In a solar cell] the light energy is changed into heat energy, which then transferring into electrical energy by the solar cell. The electrical energy is then transformed into light energy and heat energy again [by a light bulb]. 113: S7 60
>
> A. man has stored energy
> B. man uses energy to push box, transferring some to box to make kinetic energy 'cause they are moving
> C. heat energy in the air because of friction on the ground and the man's exertion (sweat) ... 114: S9 77

One multiple choice survey response (7d) explicitly described energy transformation from light to electrical to light form. It was supported by 47 of 75 respondents, including almost half the grade 9 students, even though they had not undertaken their major study of energy at the time of the survey, which includes an extended consideration of its forms and transformations. Altogether, the idea of energy forms and conversions appears on the surface to be reasonably accessible to students in this study.

Nevertheless, as discussed in connection with energy's abstract nature (section 4-1, page 149), it is less clear that students view the various energy forms as different manifestations of the same underlying quality. Many descriptions quoted above are quite compatible with a view of energy forms as essentially different things which just happen to be susceptible of change from one to the other. Turning an egg into a cake might be termed "conversion" in this sense, which is clearly distinct from the "conversion" of a dollar into some other currency. Similarly, as pointed out earlier, use of the terms "potential" and "kinetic" energy, and discussion of the conversion of one to the other, does not necessarily indicate a scientific conception of the forms or conversion process.

4.4 Energy is conserved in closed systems. During the interviews, only subject 1 consistently attempted to analyze situations in terms of energy conservation. For a simple mechanical systems, her statement was quite precise.

> There's different kinds, like, of energy that you can have, but, like, if you added them all up it would still equal the same before and after ... 115: I4 1 (062)

Situations less typical of remembered examples from physics classes gave more difficulty. Item 5 asked about the energy of exploding fireworks.

> I'd still say there was no change, but ... we haven't had that situation brought up ... I know it would have chemical potential energy of some sort there [initially] ... but then I can't figure out what kind of potential energy would be in that one [after the wick is lit]... 116: I5 1 (074)

Biological systems proved least familiar, and even more difficult to analyze.

> [A weightlifter] ... kinda has biological energy ... stuff inside him to be doing something, like ... 'cause he has to work at it. So he has potential energy to move the barbell. He has, like, energy stored in him, in his fat or something like that. // I think some of that energy in ... in him is being used up, because, like, he has to hold it ... it takes energy to hold it ... // (What happens to the energy that he had?) I don't know ... I don't really know about biological energy. I don't know where it went. He used it up ... 117: I6 1 (096-106)

Occasional survey justifications by other physics students suggested that they, too, were familiar with statements of energy conservation. However, their responses showed no evidence that they applied the principle in an analytic fashion.

> Energy totals never change, but energy forms may. 118: S4 77
>
> Energy is not destroyed or constructed. There is a "conservative energy" present. The amount of energy is constant, although the forms of energy change. 119: S5 81
>
> Either potential energy or kinetic energy is greater in each picture [of a swinging pendulum], but they always add up to an equal total ... 120: S10 84

One survey item (10e) stated directly that energy remains the same while a pendulum swings. It received moderate support (16 of 80 responses) drawn from all classes.

Taken together, these observations suggest a grasp of energy conservation that generally does not extend much beyond a regurgitated statement applied to remembered examples. This conclusion appears to support Solomon's (1982) account of both conceptual and practical difficulties associated with teaching and learning the concept, even though it is not usually considered particularly difficult.

4.5 Energy is degraded in physical changes. Only four rather imprecise suggestions of energy becoming unavailable or degraded emerged during the interviews (Table 23, page 144). Survey responses revealed that the essential role of heat energy in this process was misconstrued in several ways. For example, descriptions of energy flows through systems seldom extended to waste heat. The uncertain fate of a toy truck's energy as it moved along provides one illustration.

> ... it's being used up, probably from the wind and the ... friction, I guess // I just see it ... unwinding and the wheels are using that [energy] to make it go, I guess. (What happens as it's used up?) It just ... is, probably, no longer and it stops. It just ... I don't know ... 11: I4 3 (076-081)

The tendency of systems to move towards thermal equilibrium was not appreciated by some subjects. After hot metal is dropped in cold water,

> ... the temperature of the thermometer [in the water] would have dropped a couple of degrees and the metal would have dropped, too // (What would set the limit?) Probably zero // 'cause zero is when the, is the starting of the freezing point and the melting point ... of ice and water. 10: 13 7 (059-066)

Heat was described more than once as a carrier or mediating agent which created energy in objects. A barbell being held by a weightlifter has energy because,

> The metal ... it could be attracting heat, and the heat's making energy inside of it // It's just the amount of heat it attracts that's creating the energy in it ... 16: 16 8 (124 - 126)

These confusions, and the general lack of reference to energy degradation, appear more serious in light of Solomon's argument (op cit) for the practical utility of this concept. It provides, she suggests, a useful stance from which citizens can approach questions of resource use and energy conservation. The common conception of energy as a sort of fuel that is consumed in changes, discussed earlier, has been suggested as a suitable "anchoring conception" or jumping off point for explicit discussions of fuels in general, focussing on fuel use and conservation (Ross, 1988). Concepts thus developed would be useful "citizens' science" and could be subsumed if necessary by later studies of thermodynamics for those so inclined. The CLISP Energy materials do in fact make use of this approach (Approaches to teaching energy, 1987; Needham and Hill, 1987; Scott, et al., 1987).

<u>**4.6 Available energy can be husbanded in practical situations**</u>. Only a few references to this outgrowth of a scientific viewpoint emerged from the survey. All of them came in response to an open-ended question showing a refrigerator with door ajar.

> The fridge is having to expend extra energy that is very expensive. 121: S1 21, 71, 79)

> Someone must have left [the fridge] open not thinking that they're wasting energy. 122: S1 13, 62

The corresponding interview item showed a house with door open to the winter air. No subject described the situation in terms of undesirable energy loss.

Both elementary and senior general science curricula make explicit reference to this concept. Furthermore, the development of a conservation ethic has been widely urged as socially useful, if not essential. Energy conservation programs are widely advertised and promoted. It is, therefore, the more unexpected, and distressing, that a viewpoint which appears to be part of current culture appeared so infrequently during the present study.

<u>**Research Question 5**</u>

Will subjects consistently utilize a given conceptual orientation?

<u>**Conclusion**</u>

Neither the interviews nor the survey results produced evidence that individual students consistently chose responses which exemplified the same concept of energy. However, some notion of energy was frequently used as a descriptive framework for the open response survey question. In addition, interview transcripts did show evidence of preferred conceptual orientations for several subjects.

Discussion

Previous qualitative studies have found student responses to be situation-specific and often contradictory (Osborne & Freyberg, 1985). Thus, it was not unexpected to find that survey responses showed little evidence of consistent themes when analyzed by conception (Table 21, page 141). Two exceptions, flow transfer and conservation, were each chosen by so few subjects that any apparent consistency could easily be a chance effect. As previously discussed, however, this result is a very limited offshoot of the study, whose small scale and interpretive focus precluded sophisticated statistical analysis. At best this aspect of the present study provides no conclusive reason to doubt previous findings of the apparently fickle nature of student's allegiance to particular conceptions.

Even the spontaneous use of any sort of energy-based description was not expected to occur frequently. Duit's (1990) interview studies produced very few unprompted references to energy. The interview portion of the present study resulted in similarly negative results for items 0, 1, and 10, which were designed to test Duit's finding. Survey results were expected to be similar.

It was unexpected, therefore, to find survey item 1, depicting a refrigerator with door ajar, producing a large proportion (25%) of answers which specifically described the situation in terms of energy. An additional 45% of responses referred to specific forms of energy, mainly heat or heat loss.

It is possible that this particular situation prompted energy-based descriptions as a result of students' previous experience. Discussion in elementary science, "Energuide" labels on new fridge doors, and energy conservation advertising campaigns might all have linked refrigerators with energy. Alternatively, students might have approached the item with an energy mind-set established by leafing through the survey papers. Conversation with interview subjects in the time between interviews and survey might have produced a similar effect. In neither case would increased use of the term "energy" imply greater understanding of a scientific energy conception.

Lack of consistency in the responses that students eventually chose does not rule out the concept of preferred conceptual orientation. Subjects may have approached questions from a small number of favoured stances which, when modified by situational factors, produced a seemingly inconsistent variety of responses. The successful construction of subject profiles is taken as modest, non-statistical evidence to that end (page 143 ff). Many interview subjects' discussion seemed to show a degree of consistency in approach, even though no parallel consistency was evident in survey results. Similarly, lack of individual consistency does not endanger the idea of alternative conceptions. Responses from large groups of subjects can be grouped according to apparently similar basic ideas, even by a casual examination. Statistical analysis, although not widespread, has supported this appearance. A recent large-scale study designed to permit factor analysis has produced evidence for an underlying structure in subjects' ideas about sources of energy (Boyes & Stanistreet, 1990).

Implications of the Study

Research Methodology

The author's initial reservations about the merits of studying his own students proved unfounded. Interview subjects were more than co-operative and appeared to enjoy the experience of clarifying and expounding upon their own ideas. There was no initial reticence, and a businesslike and congenial tone was evident throughout. Survey participants, for the most part, appeared to take the exercise as seriously as it was intended. Supervising teachers reported that they pondered the items at considerable length. The resulting explanations were clearer and more detailed than the author had expected on the basis of the same students' performance on written examination questions.

The value of the preliminary steps suggested by Treagust for preparing interview and survey instruments was established in practise. A similar methodology would appear generally suitable for other studies. The systematic gathering of curriculum statements was helpful in defining an appropriate breadth and depth of expected student knowledge. Semi-structured interviews provided a stock of examples and student-generated expressions of alternative conceptions that differed so considerably from the author's perspective that they could never have been generated by his unaided efforts. The written justifications of multiple-choice survey questions suggested many further refinements to the questions which could be incorporated in the next phase of a more extensive study.

The survey results testify to the power of such instruments for revealing alternative conceptions. In classroom teaching, they appear to represent, as Treagust has argued, a viable alternative to the clinical interviews favoured by researchers. Even the preliminary form used in the present study clearly revealed differences in viewpoints which could be used as the basis for class discussion and teaching. Whether significant additional benefit would arise from recasting the instrument into the two-tier multiple choice form favoured by Treagust is uncertain. The task of wording appropriate distracters for the second (justification) level of each question seems likely to be formidable, at least for a broad topic like energy, where different conceptions tend to overlap rather than being mutually exclusive. For teaching, open responses would seem able to provoke the desired discussion of alternative conceptions. For a research study of this scope, analysis of open-response justifications did not prove to be an overwhelming chore. Only in the case of large-scale studies designed for statistical analysis would the additional step of creating a totally objective form of the instrument appear essential.

The depth of analysis employed in the study proved generally suitable for exploratory purposes. Criteria for more formalized systems of transcript annotation and conversational analysis would have been impossible to formulate until after a preliminary study of this nature. More elaborate statistical investigations would have been unwarranted until the existence and scope of alternative conceptions had been established in the target population. Moreover, the elaboration of multiple-choice responses, especially in the interview setting, revealed unsuspected nuances of understanding that were not apparent from consideration of the responses alone. The value of interview probes to establish shared understanding, which has been remarked upon by many previous investigators, also became apparent to the author in the course of the study.

However, using key words or even sentences as unit of analysis to catalogue alternative conceptions was not entirely satisfactory. The image of an energy octopus gradually emerged from the data. Students seemed to be analyzing situations with one or the other of several tenacious conceptual tentacles. The tentacles sometimes acted alone, and sometimes supported each other. The octopus as a whole was seldom visible, only twining tentacles which refused to maintain any rigid relationships.

The construct of conceptual orientation proved helpful in making sense of this sort of complex data at the octopus level of entire interviews. Emerging as it does from protracted, personal and phenomenographic consideration of the transcripts, in this case for a period of over a year, the validity of the resulting interpretations is difficult to establish on objective grounds. There is a clear danger of ascribing to the data more coherence than it contains and discerning in it structures which exist primarily in the eye of the researcher. The appropriate test, according to Johansson, Marton, and Svensson (1988) is whether the eventual crystallization of diverse and apparently conflicting findings into a coherent whole is echoed when other researchers examine the same topic. In the case of the present study, such validation is awaited.

Teaching

As a classroom teacher, the author undertook this study only partly out of academic curiosity. On a professional level, he was also concerned with improving pedagogic skills and materials. It was personally important to establish whether theories and practices developed after observations of other student populations might also apply to Alberta students.

At least in their understanding of energy, the Alberta students in this study did exhibit alternative conceptions similar to those discerned elsewhere. A wide range of distinctly unorthodox notions appeared, and despite personal variations in expression, appeared to cluster in identifiable and previously described groups. Some were openly expressed; others lurked beneath a veneer of scientific vocabulary. A basic tenet of constructivist pedagogy was being upheld: students were approaching the learning situation with a range of functional interpretive concepts. Furthermore, vocabulary and constructs taught in school science were being used to elaborate and express these preexisting conceptual frameworks, as well as their scientific competitors.

It is possible that constructivist teaching strategies and materials developed to deal with parallel situations elsewhere might be equally applicable in Alberta. In particular, teachers might be better equipped to build upon existing conceptions if given some foreknowledge of what they are. In general, it would seem appropriate that guides such as Teacher Resource Manuals and other service publications include information from the extensive literature on alternative conceptions. Teacher preparation and inservice activities for new science courses could incorporate similar information and opportunities for teachers to explore their own conceptions of significant topics.

Existing approaches to the study of energy clearly require examination. The topic has been designated a main theme of new secondary science programs, but present curricula and teaching practises apparently leave many students with little ability to use the concept of energy as a descriptive or analytic tool. A constructivist pedagogy would focus on bringing students to an awareness of their existing conceptions as an essential step in their reconsideration and reconstruction. Survey instruments such as that developed for the present study offer an entry point for this sort of discussion. The present instrument could easily be refined, and similar ones could be developed by teachers or researchers for other key topics in the Alberta curriculum.

Specific barriers to a scientific understanding of energy also emerged from the study, and with them implications of revised teaching practises. The precise scientific usage of the term "potential" energy, which has as much "reality" as any other form of energy, might better be conveyed by explicit contrast with the more ambiguous everyday usage connoting "possible, but not there at the moment." Overly differentiated notions of energy as a sort of hitchhiker attached to heat or sweat, as one of many causes of action, or as a generic term for action itself also appear susceptible to direct contrast with the more scientific view of energy as a general characteristic of physical situations. In particular, the applicability of energy descriptions to static situations involving inanimate objects is not apparent to many students and needs to be established.

Finally, some consideration of the purpose of emphasizing energy concepts at secondary school level appears warranted. Two apparently useful aspects of "citizen's science" or "scientific literacy" about this topic have been identified as a grasp of the concept of energy degradation and adoption of a conservation ethic. In the present study, both were noteworthy for their lack of expression by the students studied. Literature and activities directed specifically towards these considerations have been developed elsewhere (by the CLISP and LISP groups) and in Alberta by the SEEDS Foundation. The incorporation of these and similar materials into individual teacher's programs, or into the prescribed science curriculum can be seen as an essential step if Alberta science education is to develop a scientifically literate population. This social goal is rooted in the individual. Knowledge of alternative conceptions can help define both the starting point of relevant instruction and its eventual outcome.

Further research

If Treagust's methodology were carried further, the next step would be to use the survey data to refine both the survey instrument and interview schedule. If greater parallelism could be maintained between items, more sophisticated investigations of consistency of response could be undertaken, both from one item to another, and between the interview and survey. Revising multiple choice responses to more clearly reflect specific conceptions of energy would aid in this task.

Two major revisions of format could be undertaken. Open response justifications gathered in the present study could be used to revise the survey into the two-tier multiple choice format used by Treagust and colleagues. Alternatively, the items could be rewritten in a format which meets the constraints of factor analysis, to permit statistical investigation of possible deep structures - conceptual frameworks - underlying subjects' answers. A suitable format might resemble that devised by Boyes and Stanistreet (1990), in which subjects use a Likkert scale to indicate the extent of their belief that content-laden statements are correct or incorrect.

The study could also be extended to other populations. Parallel investigation of students who have gone through the incoming Alberta secondary science program will be possible as new high school programs are phased in from 1992 to 1994. Revised instruments could be used with younger students, before and after new elementary science programs are introduced. Such studies might shed light on the roots of connections between energy, motion, and animate beings. A third suitable population for further studies would be teachers, in view of Ameh and Gunstone's (1985) finding that they shared many of their students' alternative conceptions.

The present study could be refined and extended in its treatment of many problematic themes. Conceptions of energy as more or less substantial could be directly contrasted. Animate, non-human objects could be included in some items. Various ideas about energy's role as a prelude to changes could be stated more explicitly: is it seen as a prerequisite of changes, an accompaniment, or is it just used as a general label for change itself? Does it appear on demand, or is it actually present before a change, as a dormant ingredient or a stored fuel. What happens to energy after a change: is it consumed, released as a short-lived byproduct, or does it persist?

Two especially interesting sub-topics arise from the findings of the current study. A surprising number of students appeared to lack a functional grasp of the concept of thermal equilibrium. As it appears in discussions of physical, chemical and biological processes, this topic represents potentially useful grounds for future research. A second finding, the unexpectedly high number of students who made spontaneous use of energy descriptions (survey item 1), invites verification, especially as it stands in direct opposition to Duit's (1990) report that energy was seldom used as a descriptive concept in similar situations.

Finally, action research appears warranted in order to find appropriate ways of embedding results of alternative conceptions research in teaching practise. In particular, the present study has uncovered some possible links between alternative conceptions of energy and desired scientific understandings, as well as several possible anchoring conceptions for scientific concepts. For example, views of energy as a substantive, consumable fuel could lead to the study of energy degradation. A flow-transfer conception, by contrast, seems more allied to conservation of energy. Consideration of objects in "unnatural" situations, like a car on a hoist might foreshadow the notion of potential energy. These and other bridges from everyday to scientific conceptions need to be identified, elaborated, embodied in teaching materials, and tested for instructional utility. Science instruction and curricula resulting from such a process could be truly child-centred, respecting both the personal and social aspects of knowledge.

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Appendices

Appendix A

Letter of Permission

107 Hamilton Court, N.E.,
Medicine Hat, Alberta T1C 1J2

Dear Parent/Guardian:

With permission of Medicine Hat School District #76, I am investigating student understanding of science topics as part of a degree program at the University of Lethbridge. Your son/daughter has been randomly chosen as a possible participant in the part(s) of the project checked below.

___ An interview lasting about 20 to 30 minutes, during school time, about a particular topic. Interviews will be tape recorded so the conversation can be transcribed for study. The tapes will then be erased. Student names will not appear on the transcripts or in quotations used in reports on the study.

___ A written survey of student understanding of the topic, taking 15 to 30 minutes, during class time. Student names will be put on the papers to allow follow-up of unusual or unclear answers. After this is done, the names will be removed from the papers and will not appear in reports on the study.

Participation in the study will not affect students' grades in science in any way. It will, I hope, be interesting for them, and is certainly essential to my research project. The results of the study could be very useful in improving our science instruction in the future.

Please feel free to contact me, my supervisor Dr. Richard Butt (329 2434) or Dr. Myrna Greene (329 2424), Director of Graduate Studies, at any time if you have concerns or questions about the study. Your son/daughter also has the right to withdraw from the study without prejudice at any time.

Please complete and sign the permission slip below and have your son/daughter return it to bis/her science teacher as soon as possible.

Yours truly,

D. Gue

....

________________________ has my permission to participate in the research project described above.

Appendix B

Interview Script

Introduction

This interview is part of a research project about the way Canadian students describe different situations. I am interested in the different ideas people have, so there are no right or wrong answers. And of course, your answers here will have no effect on your mark in (name of science course).

I am going to tape-record our conversation because I won't be able to remember exactly what we say. If there's any part of the tape that you want me to erase, I can do that. Is that okay with you?

Do you have any questions before we start?

Item 0

Here is a marble. I'll hold it on the side of the ruler, here.

1. Would you tell me everything you think will happen when I let go of the marble?
2. How would you explain why the marble does that?

Item 1

In this picture, the house door has been left open on a cold winter day.

1. Would you describe as much as you can about what is happening here?
2. Is anything else happening?

Item 2

This picture shows a car balanced on top of a hoist. The car is not moving.

1. Is there anything here that you would describe using the word 'energy'?
2. Suppose someone didn't believe you. What evidence would you give that there is/isn't energy here?

Item 3a

You may have done an experiment like the one shown in this picture. A piece of hot metal is put in a beaker of cold water.

1. Tell about energy in this situation.
2. Does the energy change in any way during the experiment?

Item 3b

After several minutes, some students observe this result. The temperature of the hot metal has gone from 80 degrees down to 15 degrees. The temperature of the water has gone from 20 degrees down to 2 degrees.

1. Do you think this result is possible? Can you trust the students' observations, or do you think they have probably made a mistake somehow?
2. Does energy have anything to do with this?

Item 4a

The picture shows a toy truck, like this one. Mickey winds it up, and lets go of it. It moves along and then it stops.

1. Where is there an energy change here?
2. Where does the energy come from?
3. What happens to the energy?

Item 5

The pictures show a firecracker, the kind that explodes and makes a loud noise.

1. When does the firecracker have the most energy?
2. How do you know when the firecracker has the most energy?
3. What happens to the energy?

Item 6a

The picture shows a weightlifter holding a barbell over his head. The barbell is not moving; he's just holding it steady.

1. Tell me about energy in this situation.
2. Does the energy change in any way?
3. What happens to the energy?

Item 6b

Suppose we had different ways of holding the barbell at the same height.

1. When does the bar have the most energy?
2. How do you know it has the most energy then?
3. Some students say the energy (is/is not) the same. Why do you suppose they think that?

Item 7a

The diagram shows a flashlight battery connected to a bulb. The switch is open, and the bulb is not lit up.

1. Which part of this circuit would you describe using the word 'energy"?
2. What about the (battery/light bulb/switch)?

Item 7b

Now the switch is down, so the battery is connected to the bulb. The bulb lights up.

1. Now which part of the circuit would you describe using the word 'energy"?
2. When the switch is closed, does the energy change in any way?
3. Exactly how do you think that happens?

Item 8a

The picture shows someone using a gripper, like this one. They have squeezed it and are holding it closed.

1. Can you tell me about energy here?
2. Where does the energy come from?
3. What happens to the energy?

Item 8b

Here the athlete starts to let go of the gripper (sketch b) and here it springs open again (sketch c).

1. When is there an energy change here?
2. How would you explain that to a young child, who didn't know much about energy?

Item 9a

This sketch shows a person holding a heavy load. He is standing still at the bottom of some stairs, getting ready to carry the load up the stairs.

1. Tell about energy in this situation.
2. Do you think the energy here is any different from the energy in the last item (the grip strengthener)?
3. Explain the (difference/similarity).

Item 9b

Now the person climbs the stairs, and then rests after getting to the top.

1. Where is there an energy change?
2. Where does the energy come from?
3. Where does the energy go?

Item 10a

Let's look back at a sketch of the first example. Here is a marble on a curved track. The marble is stuck to the side of the track with glue.

1. Would you say there is energy here?
2. What do you suppose the energy depends on?

Item 10b

Now the glue breaks. The ball comes loose and starts to roll down the track.

1. How far will the ball go without changing direction.
2. Explain why you think that.
3. If you keep watching, the ball might roll around for quite a while before it finally stops. What will you see happening if you watch the ball roll for a while?
4. What sets a limit on how far the ball can go?

Appendix C

Survey Justification Analysis by Response

Question 2

The rock is balanced on top of the fencepost. Which statement below gives the best description of energy in this situation?

Response A: There is no energy here.

Although scientifically incorrect, this response was selected by almost half the grade 9 students and 31% of subjects overall. As expected, many justifications related to the absence of motion and animate objects.

> How can a fence have energy like humans do? 123: S2 9

Other justifications reflected a substantive orientation. For some, particular features of this balancing situation made it "natural" or energy-neutral:

> The rock can sit on a flat surface, especially if they are both flat. 124: S2 24
>
> The rock does not need to use up any energy to balance on the post. 125: S2 66, 69
>
> ...all is stable... 126: S2 64

Other students could find no process or reservoir which might serve as a source of energy.

> The rock is not taking in oxygen or releasing anything; therefore, there is no energy. 127: S2 67
>
> If the post did give energy, we humans wouldn't have to eat at all - we'd just have to sit on a fencepost! 128: S2 1

Several justifications mentioned gravity as a factor in the situation. However, they saw it as an alternative to energy, or merely a potential source of energy, rather than an indication of present (potential) energy.

> There is no energy being used here because there is another force at work. 129: S2 8

<u>Response B:</u> The rock has more energy on top of the post than if it were lying on the ground.

This response was selected by the majority of high school students, including almost 73% of the physics students. It parallels typical high-school science text descriptions of objects lifted above the earth's surface. Nevertheless, it is limited scientifically because it localizes the energy to the rock, rather than the rock-earth system, and because it suggests that the rock would have zero energy at ground level.

> On the ground there would be no energy 'cause it's on the ground. 130: S2 43

> On the ground there really isn't any other place lower the rock can go. 131: S2 27

Some students saw the rock as having energy because energy is a necessary ingredient for balancing, which the rock is doing, or falling, which the rock could do (depository framework).

> The [rock] can be balanced on the post, which [is] not like the ground. So the rock needs more energy to stay up there. 132: S2 3

> This rock has the energy stored up so that it can fall. If it was laying on the ground, it wouldn't have any energy. 133: S2 73

Statements of what happens to the "energy fuel" varied. It might be used up, or just given off.

> The rock has the potential to fall off the fence post and use up that energy. 134: S2 53

> If the rock was to fall, more energy would be released than if it was rolling on the ground. 135: S2 60

Many justifications differentiated between potential and kinetic energy. However, no student clearly expressed the idea of conversion between the two energy forms. Some students used the term 'potential energy' in the sense of "potential for containing energy": the rock was seen as an empty energy container which could be filled with kinetic energy created by falling. Saying that it has potential energy, to them, is apparently akin to giving the capacity of the empty container.

> On the fencepost the rock may blow over, giving it energy as it falls to the ground. 136: S2 58

> The rock has potential energy. If it falls, its energy will increase. 137: S2 79

<u>Response C</u>: The rock and post (and the earth below them) have more energy than if the rock were lying on the ground.

This is the most scientifically precise alternative, yet it was chosen by only two grade nine students. Neither justification clearly indicated an orthodox scientific viewpoint; rather, the connections expressed in the response apparently triggered a flow-transfer framework.

> The rock is forcing the post down and it is pushing into the ground. The ground is receiving all the energy. 138: S2 38

Response D: The energy of the post is being used up holding the rock.

This scientifically incorrect response was intended to trigger conceptions of energy as a fuel or necessary causal agent which is expended rather than being conserved. All but one of the responses, however, overlooked the suggestion of energy consumption and centred on the post's function of opposing the tendency of the rock to fall.

> The post has to have enough energy to hold up the rock so the post and the rock won't fall. 139: S2 6

> The post energy is holding the rock up by having it pushed up at such a rate that it stays in one spot. 140: S2 39

Energy is thus seen as the strength to resist falling.

> The post looks fairly sturdy, unlike a twig if it were in this position. 141: S2 30

Identifying energy with strength is easily linked with a conception of energy as characteristic with living things.

> The post once came from a tree, which had energy because it was alive. And even though the post is not alive, it was at a time, and its energy is being used to hold up the rock. 142: S2 35

Response E: The energy of the rock and post (and the earth below them) is being used up holding the rock.

This scientifically incorrect response was devised so that responses B and C, which speak of 'having energy', would be paralleled by responses which speak of 'using energy'. However, no justifications spoke specifically of energy use, although several students spoke of the necessary presence of energy in terms which would not exclude its consumption.

> It takes energy to hold up a rock. 143: S2 51

> It also takes energy to hold all three [earth, post, rock] together. 144: S2 44

The more common justifications focussed on energy flowing up or down through the physically connected rock, post and ground (flow transfer framework).

> The energy of the rock and post and ground below holds up the [rock] by directing energy towards balancing the rock on the post. 145: S2 34

<u>Question 3</u>

A glass of cold lemonade is left on a table on a hot day. After a few minutes the temperature in and beside the lemonade is measured by a student. The student must decide whether the measurement is reasonable. What is most important in making that decision?

<u>Response A</u>: The lemonade would not warm up so much in just a short time.

10 of 13 students merely restated the response, perhaps reflecting a comparison with personal experience rather than any attempt at considered explanation. Of the other three subjects, two applied personalized versions of particle theory.

> The air that goes into the glass would have to warm up a bunch of cold particles. It's just about the same as when a human breathes. 146: S3 2

> The lemonade wouldn't have time for the molecules to move as fast... 147: S3 22

<u>Response B</u>: The air near the glass would cool down more as the lemonade warms up.

Many of the explanations (9 of 16) focussed on 'coldness', usually described in substantive terms and going from the lemonade to the surrounding air. This process was often distinguished from the warming of the lemonade.

> The lemonade warms up, releasing its coolness, and the air around it cools down. 148: S3 12

> The lemonade absorbs heat as it gives off cool air. 149: S3 56

Two puzzling explanations suggested that the air near the cool lemonade would warm up rather than cooling down.

> The air around can only warm up, because the air from around it moves in to warm up. 150: S3 13

> The actual temperature in the environment rose, but because the thermometer was close to the glass it took an inaccurate reading of environment temperature. 151: S3 70

Two other justifications gave orthodox descriptions of energy transfer, without explaining how they would favour this response over the others.

Response C: The two temperatures would end up equal.

Without exception, explanations of this response involved heating.

> Some of the hotness will escape out into the air...warming the air up. 152: S3 7

Room temperature was often clearly identified as setting a limit to the temperature increase of the lemonade. However, the process was seen as one way, with room temperature remaining unchanged.

> Because the temperature outside the glass is 40 degrees, the lemonade must be able to reach that mark also. The temperature in the room would heat up the glass along with the lemonade within it. 153: S3 58

One student used the idea of common cause.

> The sun is warming up the air and the lemonade is outside, so after awhile they sound end up equal because the sun is heating both. 154: S3 14

Several explanations pointed to a need for extra energy if the lemonade were to become warmer than its surroundings.

> No solution would end up warmer than the surrounding environment unless outside interference had taken place. 155: S3 60

Response D: The lemonade would never get hotter than the air around it.

Three explanations cited personal experience with condensation and water.

> I've seen that in [swimming] pools the water is always colder than the air around no matter what the size is. 156: S3 35

> The glass would let off perspiration [condensation] but the lemonade would not get cold because the air around it is hot. 157: S3 50

The most detailed explanations (both from physics students) invoked conservation of energy and energy transfer.

> Heat energy can't just happen. Something needs to cause it. Nothing caused the lemonade to heat up the last 2 degrees. Nothing that hot was around to give it the heat energy. 158: S3 74

> The lemonade's particles would not end up moving faster than the air's. If heat energy is used, something has to slow down, meaning the air particles would be cooler. There is conservation of energy. 159: S3 77

<u>Response E</u>: The measurement seems reasonable but it would be sensible to repeat it just to make sure.

Only a few students attempted to explain why the measurement was reasonable, but their attempts were ingenious.

> The glass will act as a magnifying glass and the lemonade will attract the heat, so it will be warmer. 160: S3 24

> The pulp particles in the lemonade absorb the sun energies more than the particles in the air, thus making the lemonade hotter than the air. 161: S3 29

> Condensation and heat gain cause the temperature of lemonade to rise. As for the outside temperature, it is probably released from the coolness of glass. 162: S3 69

The remainder of the answers pointed to the possibility of various errors and the need to guard against them.

> You must try it twice to have an experiment, just in case the first test was wrong. 163: S3 67

<u>Question 4</u>

The bike is being pedalled along the street. The rider stops pedalling. The bike coasts along, slows down, and stops. Where are there energy changes?

<u>Response A</u>: There are energy changes from a (pedalling) to b (coasting).

Most explanations identified the source of energy as the biker (animate framework). To some, when pedalling stops, no more energy is being generated.

> The motions which caused the energy stop and the bike just coasts along, and no energy is being produced any more. 164: S4 27

To many others, stopping pedalling means energy is no longer being used up (fuel framework).

> He stopped using the energy for pedalling. 165: S4 6, 11, 26, 37

> The boy is no longer using his energy to propel the bicycle. The bike is just driving because it cannot stop on its own accord. 166: S4 4

A few thought in terms of energy transfer or release ceasing along with pedalling (depository framework).

> There is energy being released only when the bike is pedalling or braking. 167: S4 66

> When the rider stops pedalling there is no more energy being given to the wheels. Therefore the wheels use up the energy stored in its speed and eventually stop. 168: S4 59

<u>**Response B**</u>: There are energy changes from b (coasting) to c (stopped).

Many explanations overlapped with those for response A, equating lack of action by the cyclist with lack of energy.

> No force = no work done = no energy 169: S4 81

A more distinctive set of justifications focussed on factors which retard the bike's motion such as friction, wind, and energy itself.

> The pressure of the energy pushes the bike to a stop. 170: S4 13

The bike is apparently regarded as something which needs a continuing supply of energy-fuel in order to keep moving (depository framework).

> The bike begins to slow down because of a decreasing supply of energy. 171: S4 68

> There is no energy being created, but because there was energy before, it cannot abruptly stop. 172: S4 3

> From b to c energy is being lost through friction and heat. In a, any energy lost is replaced by energy from the rider. 173: S4 74

<u>**Response C**</u>: There are energy changes from a to b (pedalling to coasting) and from b to c (coasting to stopped).

Two students concisely identified energy as involved in any change. Only three offered more extended descriptions of energy conversion.

> It takes energy to do everything. 174: S4 51

> The guy has potential energy which he converts to kinetic energy. Then the kinetic energy is changed to heat energy and possible sound energy. 175: S4 42

Many explanations focussed only on the speed of the bike and its effect on energy.

> There is a loss of energy at each of the three points... If the bike was coasting there is a loss of speed and a loss of energy. When the bike is completely stopped ... there now is no motion and ultimately no energy. 176: S4 55

> Once the bike rider starts slowing down he loses energy and once he stops he also has lost energy and now is full of potential energy. 177: S4 72

Several other students made a more direct link, adopting a substantive view of energy as a thing which has speed.

> The energy slows down as the bike slows down. 178: S4 61

The changing source of energy was also mentioned.

> A person can't coast unless he pedals first, to make the energy.... 179: S4 39

> In a, human power is moving the bike. In b mechanical power is moving the bike, and in c, no power is moving the bike. The energy source changes... 180: S4 54

<u>Response D</u>: There are no energy changes.

All three students who chose this response explained it in terms of quantity of energy. One spoke in orthodox scientific terms.

> Energy totals never change, but energy forms may. 181: S4 77

The others described a balance between the energy supply from the rider and the energy demand of the bike.

<u>Question 5</u>

The string burns and the balloon explodes. When does the balloon have the most energy?

Contrary to expectations, students interpreted the question in such a variety of ways that all responses except D were able to be justified in scientific terms. If the string is considered part of the balloon, then response A is correct. If the balloon, string, and surrounding air are considered a closed system, then response E is correct. If the question is taken as referring only to the balloon and not the string, B is acceptable if heat from the burning string is seen as increasing the temperature of air in the balloon. If this process continues, response C becomes acceptable if it is taken as referring to the balloon at the instant of explosion.

<u>Response 1</u>: The balloon has the most energy before the string is lit.

Most responses focussed on the balloon, full of stored energy until it is used or released in the subsequent events.

> Energy is being stored. When the balloon blows up, the stored energy is released. 182: S5 49

> The string has the most energy before it is lit. While the fire is lit, the balloon loses more and more energy as the fire burns. 183: S5 58

Two other responses viewed the situation in distinctly animate terms.

> The molecules of energy in the balloon are bouncing from side to side trying to keep the balloon in [the] air, and therefore more energy is needed to do that. 184: S5 52

> When the string is lit the particles slow down because of the heat. 185: S5 30

Response B: The balloon has the most energy after the string is lit.

The majority of answers concentrated on the effect of the lit string on the balloon's energy, either generally or by suggesting a specific mechanism.

> The lit string gives the balloon energy until it blows up and loses all its energy. 186: S5 36

> Once the string is lit this increases the heat, which then heats up the air particles and makes them move faster, when before the air particles were just moving around as usual. 187: S5 27

> Being heated by the sun makes them [air particles in the balloon] move more quickly. The balloon can't handle it and explodes. But there's no sun in the picture... 188: S5 18

Other answers described the burning string as creating new energy, increasing the total amount present (substantive framework).

> There is potential energy, and heat energy, and motion. 189: S5 47

> Energy from inside is pushing the balloon in all directions to make it round. Also, (because) the string is lit and fire creates a lot of energy. 190: S5 29

Response C: The balloon has the most energy as it explodes.

Many answers proposed that the explosion created energy.

> Because of the explosion, the particles fly out in different directions, slamming into other particles and creating energy. 191: S5 21

> It has energy when it is blown up, but has way more as it explodes. 192: S5 46

Almost as many explanations spoke of the explosion releasing energy which was dormant or stored before the explosion.

> All the energy is shot out into many areas of the room. Pieces of the balloon go flying everywhere, too. 193: S5 25

Many students explained that energy was necessary for an explosion, but not for the other, less violent events pictured in the question.

> If it didn't have the most energy, it wouldn't have exploded. 194: S5 15

> The balloon has to have energy to explode. If not, it would just melt. 195: S5 6

> It takes more energy to explode through a balloon than keeping air inside the balloon. 196: S5 65

> Just like when a star explodes it is at its (most) brightest and strongest, and that shows there is more energy. 197: S5 32

Three students went farther, viewing energy itself as the fuel that exploded.

> It [energy] has built up and is finally exploding. 198: S5 33

Another group of answers linked energy with motion, in contrast to the static situations in other parts of the question.

> Before and after the balloon explodes, it is stable. As it explodes, little pieces are mobile... 199: S5 69

> It has kinetic energy as it explodes because the pieces are being scattered at high speed. 200: S5 78

Two physics students offered orthodox scientific explanations; one which included the concept of energy conservation, and one which did not.

> There is greater kinetic energy [in C] but great potential at B. 201: S5 70

> There is heat energy, potential energy and kinetic energy all at once. 202: S5 75

<u>Response D</u>: The balloon has most energy after the explosion.

Only two students chose this response, and neither explanation clearly explained why.

<u>Response E</u>: The energy stays the same.

Three physics students viewed the balloon, string, and air as a closed system and chose this response as describing the quantity of energy in it. One explained energy transformations1 in detail; the others quoted a memorized rule without elaboration.

> Energy changes from potential to heat (A to B) and then to kinetic (B to C) and to heat again from the explosion. There is no energy change, just transfer. 203: S5 76

Energy is conserved in an ideal system. 204: S5 82

Question 6

The person has lifted the book and is holding it still. The book can also be lifted by a machine. In which situation is there the biggest energy change?

Response A: The biggest energy change is when the book is lifted by the person.

Some students emphasized the contrast between living person and non-living machine.

> The person is alive. We have lots of energy, and when we use a little, lots has to be made. 205: S6 44

Other explanations associated energy with the source of the person's ability to lift the load, but not with the machine's fuel.

> When the person eats, he uses the energy in the food (calories) and converts it into energy that will lift the book, battling the force of gravity. The machine just uses electricity. 206: S6: 1

> When a person lifts the book there is an energy change because they are using their strength, but a machine is just using power. 207: S6 14

> Potential energy that is stored by the body is converted into kinetic energy as the book is being lifted. The machine has no stored energy. 208: S6 42

A large group of explanations pointed out effects of work that are evident in humans but not in machines. These were offered as evidence of greater energy use by people.

> It affects a person more... 209: S6 37

> The person is creating more energy because soon he will start sweating... 210: S6 16

Some answers suggested that humans must use energy as a substitute for the superior capabilities of machines.

> Humans would put most of their energy into their arm so they could hold the book... A robot arm doesn't transfer any energy because he's made of metal. 211: S6 9

> A machine is constantly on, so there would be no change, but when a person lifts it, lots of blood and energy will go to that arm to help it lift the object. 212: S6 24

A final set of students pointed out that holding the book still requires continual energy use by the person, but (possibly) not by the machine.

> The person is using energy to hold the book up in addition to the gravitational potential energy. 213: S6 84

> It takes more energy for a human to hold a book still than for a machine. 214: S6 0

<u>**Response B**</u>: The biggest energy change is when the book is lifted by the machine.

One group of answers associated energy only with the fuel or mechanism used by machines. Human action does not require energy.

> The machine uses fuel to lift it; we don't. 215: S6 4

> A person uses muscles to lift something, but a machine uses wires... 216: S6 2

A second cluster of answers hinted that operation of a complex machine must require more energy than the apparent simplicity and directness of bodily action.

> It [the machine] is only able to work (only) by energy being in it through electricity or something, and that'd be much more than a person just picking it up. 217: S6 54

<u>**Response C**</u>: The energy change is the same for both ways of lifting.

Most answers disregarded the type of lifting agent and focussed on the identical initial conditions, action, or final result. Height was mentioned most often (8 of 17 answers), but other factors were identified.

> The book would not change its weight; therefore, the same amount of energy would be required. 218: S6 57

> Energy depends on the mass of the book, the height lifted, and the gravitational pull of the earth. 219: S6 60

> The book is being lifted in both cases. 220: S6 10

> If there was no energy the book would have fallen. 221: S6: 20

One student traced the energy involved to a common source.

> In order to get energy we must live in the sun and get the energy from there. And I think it will stay the same. 222: S6 18

Another explanation could not quite reconcile apparently the apparently incommensurable situations.

> It takes muscle and energy for a human to lift it, but it only takes a few spare parts and electricity for the machine. So I don't know. 223: S6 12

A physics student offered a concise analysis of two views of the situation.

> The book has the same amount of energy. The person may arguably have more energy, since he needs muscle to hold the book up, but that is transferred to heat energy.... 224: S6 77

Response D: There is no energy change when the book is lifted.

Only two students chose response D. They apparently interpreted the question as referring to the form of energy involved in the lifting, which was taken as kinetic in both cases, and thus was unchanged.

Question 7

This solar cell is connected to a light bulb, but a cloud shades it from the sunlight. Which description best fits your idea of energy in this situation?

Response A: Sunlight releases the energy of the solar cell, so the bulb lights up.

Several students restated the key feature of this response, that the source of energy is the solar cell, sometimes adding more detail to the process. Two other students saw the solar cell as transferring sunlight to the bulb without any apparent transformation or energy involvement.

> You need some light for the light bulb, so that [sunlight] is an easy way.... 225: S7 43

Response B: Electricity produced by the solar cell makes the bulb release its energy and light up.

Again, one student explained the process in terms of heat.

> The sun heats the solar cell up and the bulb lets off light energy. 226: S7 50

Another answer saw the bulb using energy produced by sunlight, but with no suggestion of energy transfer (fuel framework).

> The sunlight's raise (rays) produce energy so the light can shine, but when there is no light the bulb uses up all the energy and slowly dies out. 227: S7 25

<u>Response C</u>: The electric current in the circuit gets "charged up" with energy in the solar cell and carries it to the bulb, which lights up.

Of the students who chose this response, one explanation identified the bulb's light with sunlight, but with an energy boost from the solar cell.

> The sun is trying to make the light lite (sic) up but it won't. The solar cell gets all energized up and produces a energy for the bulb. 228: S7 31

Two students pleaded ignorance.

> Sounds good! Not sure why. 229: S7 16

<u>Response D</u>: Light energy from the sun is changed into electrical energy by the solar cell, and then back into light energy by the bulb.

The majority of students choosing this response made no comment. Of those who did, two spoke of a physical transformation of the sunlight.

> When sunlight hits a solar cell it changes to electrons and then flows into the bulb's current, which causes light to appear. 230: S7 2

Two students spoke of the circuit in terms of energy storage and release (depository framework).

> The stored light energy is being blocked by the cloud. Therefore the energy is being stored until the cloud is gone. 231: S7 49

One physics student proposed an analogy to photosynthesis.

> It reminds me of photosynthesis. Light energy is converted to another type of energy (here it is electrical, in photosynthesis it is chemical) and then the energy is put back into the system.... 232: S7 80

<u>Response E</u>: Electrical currents from the solar cell go through both wires, meet in the bulb, and react to produce light energy.

Two explanations for this choice were given, one of which clearly accepted it.

> It's like plugging in a lamp into a socket. Energy is reacting to produce light energy. 233: S7 12

<u>Open response suggestions</u>. Two responses added heat as an element in the energy transformations.

> I think the light energy is changed into heat energy, which then transforms in(to) electrical energy by the solar cell. The electrical energy is then transformed into light energy and heat energy again. 234: S7 60

Two other students located the source of energy in the solar cell, with the sunlight as an assist.

> The energy is really more from the solar cell...but it never could have done it without the sunlight. 235: S7 26

Several explanations treated energy in substantive terms, as a thing which can be transported and stored.

> I think the light energy from the sun is stored within the solar panels and then transported to the bulb, lighting it up. 236: S7 58

> The sun is energy and energy can be electricity, and it bounced off the solar cell, went through the wires, then lit the bulb. 237: S7 9

Question 8

A person is holding a ping-pong ball under water. The person lets go and the ping-pong ball pops to the surface. Which part of this situation could be described using your idea of energy?

Response A: There is energy only in part A, where the person is forcing the ball to stay underwater.

Many answers saw energy only in the work done, or force exerted, by the person against the resistance offered by the ball.

> The person is manually holding the ball under. I think it is just human energy. 238: S8 11

Other explanations identified energy in several aspects of the situation.

> Most energy is from the person. Knowledge of holding the ball down and when to let go takes energy. Sure, energy is used as it come to float on the surface, but not as much energy [as] humans use. 239: S8 65

Two answers differentiated between energy and energy use, or energy release.

> The person is holding back the energy of the ping-pong ball, and while pushing against the ball's energy, he is using up energy. 240: S8 64

> There is energy in (a), but it's not released until (b). 241: S8 46

One student considered energy to be created by the situation (fuel framework).

> When the person holds the ping-pong ball down energy occurs because the ball wants to get to the surface, forcing against the water. It would take a lot of energy to do that. 242: S8 20

Several explanations focussed on a transfer of energy from the person to the ball (flow-transfer framework).

> The person is exerting energy on the ping-pong ball, the ball is absorbing energy until it is released. 243: S8 60

Four answers used the term "more energy" without specifying the comparison. It is not clear why these students did not choose response (D).

<u>**Response B**</u>: There is energy only in part (b), where something is moving.

The majority of explanations expanded on the movement cue.

> No movement, no energy. 244: S8 69

The violence of the motion was noted by two students.

> All of the pressure from the water is pushing up the ball. When it touches the top of the water it's like an explosion. 245: S8 25

Two students described energy as moving with the ball, but distinct from it (substantive orientation).

> The ping-pong ball is moving to the surface and all the energy is moving up. 246: S8 14

Two explanations linked movement with the creation of energy (ingredient/by-product framework).

> When the person is holding the ball there's no energy and when the ball is just floating there's no energy, but in (B) the ball is moving, pushing the water out of the way, causing energy. 247: S8 27

In addition, the movement was seen as requiring or using energy.

> Because the ping-pong ball is moving there is energy. The ping-pong ball is using energy to go to the top of the water. 248: S8 28

Response C: There is energy in part C, where the ball is at a higher level and the person is (a bit) tired.

None of the three explanations for this answer choice gave clear reasons why it was preferable to other responses.

Response D: My idea of energy applies to more than one part.

Many explanations merely restated the situations depicted in the question, sometimes classifying them as showing kinetic and potential energy. Another large group spoke of energy use, by the person, ball, and/or water (fuel framework).

> In (a) the person is using energy and in (b) the ball and the water are using energy. 249: S8 45

> The person uses energy to hold it underwater and the water is putting out energy by rising the ball to the top. 250: S8 22

One student combined energy use with energy creation.

> I think that it takes energy for the person to hold the ball down, but I also think that the ball coming up at such forces creates a sort of energy. 251: S8 33

Three explanations were in terms of energy release, rather than use (ingredient/by-product framework).

> Energy is being released as the ball is held down and as water resists it coming up. 252: S8 66

> Water is constantly giving off energy. 253: S8 67

Several physics students were able to write detailed orthodox analyses of parts (b) and (c) but were not as specific when describing part (a).

> In (a) energy is like potential gravitational energy except in the opposite manner. There is a potential for the ball to float, but the person is preventing it, so energy is present. In (b) there is kinetic energy 254: S8 76

Response E: There is no energy here at all.

One answer was unclear. The other three explanations identified causal agents other than energy for the motion of the ball.

> It is merely air in the ball making it pop to the surface. 255: S8 12

> Only buoyancy, and I'm not sure if that is considered energy. 256: S8 32

<u>Question 9</u>

The person pushes the box up the hill and then sits down to rest. Which description best fits your idea of the person's energy as the box is pushed up the hill?

Response A: Energy is being produced in the person's body so the work can be done.

The largest number of explanations viewed energy as produced in order to perform a task (functional framework).

> Energy has to be produced so the box can be pushed up the hill. No energy is required to rest or get ready to push it. 257: S9 4

> The energy ... is the boy getting ready to lead the box up the hill. He is making his energy to do work. 258: S9 31

One student contrasted the particular task with a background of normal activity.

> Energy is being produced by the person because they're using energy they really don't use everyday. 259: S9 34

Other answers associated energy directly with movement or change of position.

> The person uses a force to move up the hill, which is also work, so energy is produced. 260: S9 78

> If there was no energy, the box would still be at the bottom of the hill. 261: S9 28, 73

The source of energy was localized to the person, rather than the box (animate framework).

> The person is using all the energy to push the box up because even if the box had energy it can not push itself up. 262: S9 24

Several students traced the energy production back farther, one to muscles, and two back to food (depository framework).

> In our bodies we have stored food and energy. When we need energy it is either made or already made so it can be used. To have lots of energy, eat healthy. 263: S9 33

<u>Response B</u>: Energy is being transferred from the person into the box.

The largest number of explanations attempted to identify an intermediary in the transfer process. Muscles, force and work were all proposed.

> Energy is being transferred from the person to the box by the person's muscles. 264: S9 2

> The work the person does by giving it [the box] distance and force causes the box to have kinetic energy. 265: S9 76

Various reasons were given to support the conclusion that energy moves from the person to the box. Two answers embodied the view that the box must have energy in order to move.

> If the energy only stayed in the person then the box wouldn't move. It has to be pushed up by the energy of the person to the box. 266: S9 40

> The person gives the box energy. That's the only way it is going to get up the hill. 267: S9 46

Other students spoke of energy use in a manner which implies conservation: used energy must go somewhere (flow-transfer framework).

> Energy is being used when the box is being pushed up the hill, transferring the energy to the box. 268: S9 61

Several descriptions of energy transformation were offered in orthodox scientific terms. However, they considered only the person and the box, not the surroundings.

> Energy that is stored in his body is converted and transferred to the box, as well as moves (moving?) him up the hill. As this happens both him and the box gain gravitational potential energy. 269: S9 274

> The man does work on the box to push it uphill as well as overcome the force of friction. Therefore, energy is transferred. 270: S9 83

Response C: Energy is being shared between the box, the surroundings, and the person's body.

Two students considered the mass of the box and the ground's ability to support it to be evidence of energy when justifying this answer.

> The person is using energy pushing the box up the hill. The box is heavy, so it also has energy. The ground has energy also, because it's holding up the box and person. 271: S9 41

Two explanations included overcoming friction as an energy-consuming aspect of the situation.

> The most energy comes from when everything is touching or moving. Because of friction and all the things you are going up against. 272: S9 54

Two physics students gave concise elaborations of how energy is distributed in this situation.

> Energy is being transferred from the person to the box. However, because of frictional effects, some of the energy is also being transferred to heat energy. 273: S9 82

Response D: Energy is being used up pushing the box.

The majority of explanations proposed the necessity of energy to accomplish either this particular task, any task that is more strenuous than normal activity, or anything at all. They accepted that the energy was used up and did not elaborate on its fate.

> You have to use energy to do anything, no matter how big or small the task is.... 274: S9 23

> When the person pushes the box [he] uses more energy than when he rests at the beginning and end. 275: S9 0

> The person needs energy to push and after he's done pushing he's lost his energy. 276: S9 37

Another group of answers offered evidence of energy use: the person is tired after performing the task. Again, no comment was made on what happens to the energy.

> ...it takes a lot out of a person, you know. 277: S9 26

Two students traced the source of the energy to muscles and to food, respectively. Three others spoke of it being produced as if from a reservoir. After being released, in their view, it is available for use.

> The stored energy in the man is getting ready to be released to push the box up the hill. 278: S9 49

> At the same time he's releasing energy, he's using it up to push the box. 279: S9 67

Rather than production and use, one explanation pictured a process of temporary focussing of diffuse energy in order to accomplish the task.

> He needs his energy in his arms and legs to help him walk and to help him push up the hill. Then all his energy starts to relax when he's at the top of the hill. 280: S9 9

Response E: My idea of the person's energy is different from all of these.

Two students viewed the pushing process as creating energy of itself, separate from the production of energy in the person's body.

> I think that there's energy being produced in the person to push the box, but there's also energy produced while he's pushing the box up the hill. 281: S9 27

Another proposal suggested the presence of active opposition to the motion of the box, possibly a sort of opposing energy.

> Energy is being exerted on the box to push it up the hill, but the hill and box (environment) are working against it. 282: S9 71

One student took an extremely functional view of the situation.

> I think he should pull the box up the hill. But if he had time and money he could make a conveyor belt. 283: S9 11

Question 10

The pendulum is glued to the wall. The glue breaks, and the pendulum swings down and then up again. If we measured the pendulum's energy, our answer would be ...

Response A: The pendulum's energy would be highest in (A - glued to the wall) and go steadily down as the pendulum swings.

Three answers identified energy with speed of the pendulum. Seeing the speed as fastest immediately after the glue breaks, they concluded that energy was highest then.

> The pendulum slows down as it swings; therefore, energy is highest at (A). 284: S10 66

Two students suggested that maintaining the unnatural position of the pendulum in (A) required energy in the glue (depository framework).

> The energy would be the glue trying to keep the pendulum to the wall. The pendulum [is] trying to break it so hard that the energy is being used up.... 285: S10 31

Four other answers used similar reasoning, but located the energy in the pendulum rather than in the glue.

> There is a lot of energy in (A), as the pendulum gets ready to become unstuck from the wall. 286: S10 68

> The pendulum needs its energy to break free, then swing, but as it starts to climb it needs its energy again. 287: S10 9

The largest number of explanations treat energy as necessary for swinging, but they proposed two ideas about where the energy came from. Some saw the pendulum accumulating it until there was a large enough amount to start moving; others saw the action as producing energy (ingredient/ by-product framework).

> The pendulum is storing its energy up and then it goes down and uses its energy up as it swings back and forth. 288: S10 7

> The potential energy is high and the pendulum wants to break off the wall and swing, which would produce less energy. 289: S10 55

Response B: The pendulum's energy is lowest in (A-stuck to the wall) and goes up as the pendulum gathers energy to swing.

Most answers explained that energy is necessary for motion. Moving objects, in one view, are said to "use energy". However, the chosen response requires that their energy increase. There is no contradiction if "using energy" is taken in a descriptive sense, as meaning "energetic" (see Discussion, above).

> It (energy) would be lowest in (A-stuck to the wall) because it's stored. When it (pendulum) lets go it is in motion, so it's using energy. 290: S10 41

Three students differentiated between upward and downward movement in very similar terms. However, it is not clear how their analysis supports the chosen response.

> It takes more energy to go up than it does to go down, so after it has gone to (C - end of first oscillation) it (energy) will be lowest...because the ball has to fight gravity to get up. 291: S10 33

Another group of explanations had the pendulum creating energy as it moves, either gradually or suddenly.

> ...it swings down and gathers energy as it moves until it stops. 292: S10 12

> All the pressure of it being tied up is released when the glue unsticks. 293: S10 63

> It is like getting a push to give it more swing. 294: S10 16

The energy rise was described both as a necessity for, and as a byproduct of the motion.

> The pendulum needs energy to swing back and forth. If it is glued no energy is used because it is stuck there.... 295: S10 14

Energy rises more when there is motion rather than sitting still. 296: S10 50

Response C: The pendulum's energy would be high in (A - stuck to the wall), go down as the pendulum swings lower, and then go back up in (C - pendulum rises again).

Three students described a cycle of energy accumulation, use, and replenishment in neutral terms, as accompanying its motion.

> There is high potential energy in the pendulum. At first energy is released and it swings. As it climbs, it gains energy and starts its descent again. 297: S10 62

Three other descriptions were framed in more active terms, suggesting that energy becomes available to the pendulum on demand, in proportion to the difficulty of the task.

> The pendulum is trying to get away from the wall. When it does, it basically free-falls until it has to fight against the gravitational pull. 298: S10 63

A still more active description portrayed energy as creating a force to move the pendulum.

> Energy pushes the pendulum in order for it to swing forward. 299: S10 13

As in the second quotation above, many students identified the initial high energy state with the need to break the glue, rather than interpreting the energy changes entirely in terms of motion. When the pendulum does begin to oscillate, downward motion was described as a low-energy activity, while moving up was associated with higher energy, as in the first quotation above.

One physics student attempted to describe a kinetic-potential energy transformation. However, his description only supports this choice of response if the two forms are not considered quantitatively equivalent. Energy would thus be transformed, but not conserved throughout the motion.

> There is both potential and kinetic energy in (A -stuck to the wall), but as the pendulum comes closer to (B - low point) the potential energy decreases and the kinetic energy increases. At (C - end of first oscillation) the energy is almost the same as (A) because there is both kinetic and potential energy. 300: S10 75

Response D: The pendulum's energy would be low in (A - stuck to the wall), go up as the pendulum swings faster, and then go back down in (C - end of first oscillation).

Many explanations were in terms of speed or momentum (see Discussion, above) with the connection to energy left implicit.

> Gravity pulls on the pendulum and makes it travel faster. The as it goes up it slows.
> 301: S10 21

Other answers explicitly associated speed (or momentum) with energy, energy use, or energy creation.

> As the pendulum swings from the wall it gains speed and energy, but as it begins to rise again the force of gravity takes some energy away. 302: S10 81

> As it [pendulum] picks up momentum, more energy is used. 303: S10 (0

> As the pendulum moves faster, the more energy is created. 304: S10 9

Two students associated energy changes with the direction of motion, rather than its speed.

> It gathers energy as it swings so it can go back up in (C). 305: S10 73

<u>**Response E**</u>: The energy of the pendulum would stay the same.

Two students defended this choice by explaining that no energy was involved in the motion, since another "causal agents" was acting.

> It is using no energy at all. It is using the force of gravity. 306: S10 4

Two answers stopped at naming a type or effect of energy in each part of the pendulum's motion, but four others explicitly stated that the amount of energy stayed constant.

> Either potential energy or kinetic energy is greater in each picture, but they always add up to an equal total. 307: S10 84

One student described the situation as one of energy conservation, but apparently intended the everyday meaning of husbanding energy (or, more correctly, fuels).

> The energy is conserved, then lost as the pendulum is released. 308: S10 58