Science Education in International Contexts

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The Hong Kong Institute of Education

and

Winnie W. M. So (Eds.)
The Hong Kong Institute of Education

This book presents an international perspective on examining and putting into practice new innovations in science education. The chapters are organized into three parts, each of which addresses a key area in science education research. Part I of this book (Students' conceptual understanding of science) addresses issues related to the identification of students' science concepts, and the influence of everyday understandings on the construction of science concepts. Part II (Making science concepts plausible for students) addresses the pedagogical concerns of teachers in making science ideas plausible and logical for their students. Part III (Science teacher learning) reports on science teacher learning in Australia and Hong Kong. The focus is on the interaction between research and implementation, or how theory can be realized in classroom practice, with contributions from both non-Western and non-English-speaking contexts and Western and English speaking countries. Taken together, the papers have a common focus on the relationship or integration of theory and practice in science education. They demonstrate a concern to address education reform directions, putting into practice recommendations from science education research, and improving the quality of science education.

The contributors of this book come from seven different areas around the world. These contributions have been essential in making the discussions in this book multi-perspective and relevant to an international audience, thus allowing it to emerge to join the international discourse on improving science education. The studies reported in this book provide insights for future research addressing science education reform directions, students' learning needs and different classroom contexts. The discussions and the findings reported are relevant to science educators, teachers, student teachers, graduate students in education, curriculum developers and those responsible for education policy.
Science Education in International Contexts
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Edited by

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PREFACE

This book presents an international perspective on examining and putting into practice new innovations in science education. The chapters are organized into three parts, each of which addresses a key area in science education research, namely innovations in science teaching pedagogy, studies of students’ science conceptual understandings, and science teacher education. The focus is on the interaction between research and implementation, or how theory can be realized in classroom practice, with contributions from non-Western and non-English-speaking contexts.

Promoting the quality of science education is a major concern of science educators and teachers in Hong Kong. The present volume is the result of a decision after a conference on science education organized at the Hong Kong Institute of Education, to appoint a team of editors to produce a volume of selected papers that reflect international perspectives on science education. It contains revised versions of about one in five of the papers presented at the conference. All of the papers published here went through multiple reviews. Their organization into the various parts of the book was based on their major themes. Taken together, the papers have a common focus on the relationship or integration of theory and practice in science education. They demonstrate a concern to address education reform directions, putting into practice recommendations from science education research, and improving the quality of science education.

The editors thank all of the contributors of this book for their enthusiasm and collaboration, and the reviewers for their hard work in reviewing the papers. These contributions have been essential in making the discussions in this book multi-perspective and relevant to an international audience, thus allowing it to emerge to join the international discourse on improving science education.
This prologue has two aims. First, it sketches out the issues and pedagogical concerns arising from science education reforms. Second, it addresses critical challenges for science educators. The prologue provides a context for the selected contributions.

ISSUES AND PEDAGOGICAL CONCERNS ARISING FROM SCIENCE EDUCATION REFORMS

Having reviewed recent educational reforms and standards-based movements in education in different countries, Wang and Odell (2002) have come to the conclusion that, although these reforms have particular objectives and specific content, they share common implications for teaching. Among the reforms, the importance of students’ deeper understanding of concepts and the relationship of concepts within and across various subjects is emphasized, while those for memorization of facts and theories are reduced (Cohen, McLaughlin, & Talbert, 1993). The second similarity conforms to Resnick’s (1987) proposal that teachers need to challenge students’ misconceptions and to connect students’ learning with personal and real-life contexts. The importance of letting students share their ideas and examine their learning through discourse (Leinhardt, 1992) is also one of the common emphases. Teaching is defined as facilitating students to actively construct their own concepts. Teachers also need to cater for the diverse needs of students, whatever their gender, race, or social, cultural or economic backgrounds.

The learning theories underpinning these reform directions are the constructivist and the socio-constructivist views of learning. According to these views, the learners have prior ideas that may influence their subsequent learning. Learning is forming linkages between what the learner already knows and the new knowledge. Knowledge is actively constructed by the individual, and images of the world are formed as a result of this construction (Anderson, Reder and Simon, 1996). In personal constructivism, learning is seen as an active process as the individual learner makes linkages between existing ideas and new ones. Moreover, the learner has to assume the major responsibility in learning and mental processes. The individual is seen to have agency, that is he or she can decide or not decide to change their existing conceptions.

Driver, Asoko, Leach, Mortimer, and Scott (1994) described the construction of science knowledge in the classroom, and related how the students are socialized into the community of science by the teacher. A sociocultural view considers learning as influenced by the sociocultural context, emphasizing the participation of individuals, the interactions between them, and the construction of knowledge.
through their interactions (Salomon & Perkins, 1998). This includes the Vygotskian perspective that learning depends on interaction between the child and the more competent others (Howe, 1996). According to these perspectives, the culture and the social interactions are important parts of the learning. Learning can be seen as a socialization process into a new culture through the use of cultural tools such as signs, languages, and computers.

These views redefine learning and hence pedagogical strategies to facilitate student learning. Efforts have been made by science education researchers to identify students’ alternative conceptions in science (Deadman & Kelly, 1978; Schaefer, 1979; Tamir, Gal-Choppin, & Nussinovitz, 1981) as well as ways to change them (Lyle & Robinson, 2002). Researchers (Bell, 1981; Trowbridge & Mintzes, 1985) have identified the influence of everyday understandings and language on the construction of science concepts. These findings point out the importance of social and language contexts in considering students’ prior concepts, and in identifying ways to make science concepts plausible for the students. Part I (Students’ conceptual understanding of science) of this book addresses issues related to the identification of students’ science concepts, and the influence of everyday understandings on the construction of science concepts.

Part II (Making science concepts plausible for students) of this book addresses the pedagogical concerns of teachers in making science ideas plausible and logical for their students. An understanding of the era, culture and scientific community is essential for making sense of science and scientific research (Kuhn, 1996), as science itself is influenced by culture (McComas, 2004). Kumashiro (2001) observed that Western science is learnt in schools, and recommends that teachers help students to look beyond what is being learnt, and invites students to learn science in other contexts. Learning science in contexts that are relevant to students’ lives is beneficial to them as they can then consider different kinds of problems and answers using a different approach which is relevant to their experience. Consistent with these arguments, science teachers can choose to adopt a number of teaching strategies including inquiry learning, science, technology and society education (STS), and ways to enhance students’ understanding of the nature of science (NOS). Inquiry learning and STS strategies can provide students with opportunities to consider science concepts in real-life contexts. Here the contexts of non-Western societies are relevant to the construction of the teaching and learning activities.

Nurturing students’ understanding of NOS helps them to make sense of scientific research, and provides them with a framework for constructing science learning. While there has been research that has evaluated the beliefs of NOS held by teachers and students, Lederman, Abd-El-Khalick, Bell and Schwarz (2002) call for studies that focus on individual classroom interventions aimed at enhancing students’ NOS views. This suggests a line of research that is formulated to identify pedagogical approaches for teaching NOS. Part II also addresses this concern with a case study of a junior secondary science class in Hong Kong, and the attempt of a group of science educators to integrate NOS and STS learning at senior secondary level.

The development of learning and thinking skills is also a concern among science teachers. In Part II of this book, a study which tested out strategies to
promote high level thinking among junior secondary science students is reported (Chapter 4). Moreover, science education researchers from Singapore work to capture students’ thinking in inquiry activities and provide practical suggestions on how the development of reflective thinking skills may be embedded in science lessons (Chapter 8).

The concerns about the participation of female science learners and gender-related differences in science learning are consistent with the socio-constructivist view of learning, which emphasizes the participation of individuals and the influence of the socio-cultural context. Chapter 9 describes the design of a teaching strategy that addresses the learning needs of female physics learners.

CRITICAL CHALLENGES FOR SCIENCE EDUCATORS

The first two parts have identified important issues for science teachers to consider in facing the challenges of education reform. The analysis of conceptual changes in Part I is consistent with a personal constructivist view of learning, while the discussions in Part II are in line with a socio-cultural view of learning. Having considered conceptual changes among students, classroom innovations, different ways of mediating science learning, and addressing gender-related learning issues, the discussion cannot be complete without a consideration of concerns of the professional development of science teachers. Despite the fact that researchers have suggested a number of teaching ideas, teachers may not completely subscribe to the reform directions or the innovation suggestions due to personal or contextual constraints in their teaching. In a study on the assessment practices of science teachers (Cheng & Cheung, 2005), the findings suggested that while the teachers made attempts to address the education reform, they in fact retained their previous practices. While the teachers were ready to adopt a wider range of student work formats, they were shifting these innovations to be undertaken by the students after lessons, on top of the usual assignment of homework. Teachers are at a crossroads in determining whether they need to adopt new and old practices at the same time, or if they can integrate new ideas into their existing practices, or if they should revert to their old practices having found it too difficult to make the changes.

Part III (Science teacher learning) of this book reports on science teacher learning in Australia and Hong Kong. Chapter 10 invites science teacher educators to view practice from a science teacher learning perspective, and suggests that science teachers articulate and share their professional knowledge through the use of cases. A particular area of science teacher learning is analysed in the other two chapters. Various authors from Hong Kong, where the drive to incorporate the use of Information and Communication Technology (ICT) in teaching is strong, join the effort to examine teachers’ ICT competency and their beliefs in incorporating ICT into science classrooms.

The contributors to this book have worked to share their experiences of researching science education and teaching science in their specific classroom contexts. These studies may provide insights for future research that addresses science education reform directions, students’ learning needs and different classroom contexts.
REFERENCES


PART I: STUDENTS’ CONCEPTUAL UNDERSTANDING OF SCIENCE
INTRODUCTION

One of the most important aspects of science teaching and learning relates to student development of conceptual scientific knowledge. According to Brown, Colin, and Duid (1989), conceptual knowledge is a function of culture and the activities of the community in which the concepts have been developed. With the development in focus towards social constructivist and sociocultural research in learning, there is a suggestion that the cognitive activities of individuals can be understood by examining the social and cultural contexts from which they are derived (Coll, France, & Taylor, 2005). The sociocultural view is that understanding science is assumed to be inherently situated with regard to cultural, historical, and institutional contexts (Packer & Goicoechea, 2000; Wertsch, 1995). This view relates to the idea of situated cognition (Hennessy, 1993). Situated cognition means that cognitive processes differ according to the domain of thinking, and the specifications of the task context (Coll et al., 2005).

Energy is used in everyday life and also in different contexts; scientific conceptions of energy might be perceived in various ways. Much research has studied students’ energy concepts related to what they perceive in everyday life. Studies in the English language context (Watts & Gilbert, 1983; Solomon, 1983; Brook & Diver, 1984; Bliss & Ogborn, 1985; Gair & Stancliffe, 1988) have generally resulted in a considerable percentage of human-centred ideas of energy, and of associations with food. Findings from Germany (Duit, 1981) however, have shown that the framework of human-centred energy is very infrequent. Findings from Israel (Trumper, 1990) and the Netherlands (Lijnse, 1990) have commonly shown a high percentage of the idea of energy in terms of fuel. Findings from Thailand (Sengsook, 1997) have also shown a similarly high percentage of the idea of energy in terms of fuel.

Students’ alternative frameworks of energy in different countries and cultures show that their ideas of energy are related to their experiences of society. Electrical energy is related to everyone’s experience. There are social issues that are related to electrical energy, for example, campaigns for saving electricity. Obviously, the social issues affect learning about energy in school; students seem to understand the law of energy conservation as saving energy (Duit, 1984; Solomon, 1985; Carr & Kirkwood, 1988; Trumper, 1990). It could be said that the layman’s concept of energy is related to
energy saving and generating power. These correspond to the concepts of the law of energy conservation, energy transformation and degradation which might be confused by the socialization process.

In the scientific view, energy transformation involves the concept that energy can occur in several forms, and it can be converted from one form to another (Duit, 1984). The law of energy conservation is the concept that the total energy of an isolated system always stays the same, regardless of any processes occurring within the system. When energy is transferred from one system to another, or when energy is transformed from one form to another, the amount of energy does not change (Duit, 1984; Hobson, 1982). Energy degradation is the simple concept of entropy (Duit & Haeussler, 1994). Entropy is an energy concept that looks at the second law of thermodynamics from the atomic point of view. Using the concepts of thermal energy and temperature, entropy is given the meaning of the concept of disorganization. The disorganization in the isolated systems can easily become more disorganized, but those systems can become more organized only with outside assistance (Hobson, 1982). As with the simple concept of entropy, therefore, the concept of the degradation of energy involves the processes taking place in closed systems where the amount of energy does not change, but the usefulness of the energy inevitably declines and is hard to reverse to become more useful (Duit & Haeussler, 1994).

With a focus on social constructivist and sociocultural learning, student concepts of the law of energy conservation, energy transformation and degradation may be developed by considering the social contexts in which they are embedded. This learning perspective suggests that teaching and learning have to focus on the thinking of students in different cultures and countries (Wertsch & Toma, 1995) such as Thailand and New Zealand. The students in Thailand and New Zealand, therefore, are situated to learn science by their different socialization processes. Scientific knowledge has been developed in, and is rooted in Western countries. New Zealand is a Western culture; students there might be familiar with science learning, but they might also be confused by the differences in meanings between everyday language and scientific terms (Solomon, 1985). In Thailand, a non-Western country, science learning is translated from Western languages, so there might be a gap between the translation and the culture of the development of conceptual knowledge. Perhaps comparing the ideas of New Zealand and Thai science students may give empirical evidence of how the different cultures influence their existing ideas of the teaching and learning of the law of energy conservation, energy transformation, and degradation. These findings may have implications for teaching the energy unit developed and evaluated for Thai students.

METHODOLOGY

Subjects

The participants were 42 Grade 9 Thai students from the city of Khon Kaen in Khon Kaen Province, and 30 Grade 9 New Zealand students from Hamilton. The New Zealand group comprised of 85% European, 12% Maori, and 3% Asian students.
The Development of the Research Instrument

A purpose-designed instrument, the Questionnaire of Student Energy Conceptions (QSEC), and interviews were used to collect the data. The QSEC aims to explore students’ frameworks of energy concepts, and students’ existing ideas of the law of energy conservation, energy transformation and degradation. The QSEC was developed by setting the purpose, constructing the questions, having an expert panel check content validity, and piloting. The QSEC was designed to explore student energy conceptions related to their everyday understanding, in order to provide information for meaningful energy teaching. The questions were asked to explore the following areas: (1) students’ frameworks of energy concepts, (2) students’ understanding of energy formation, (3) students’ understanding of the law of energy conservation, (4) students’ understanding of energy transformation in generating power and electrical devices, and (5) students’ understanding of energy transformation and degradation. The questions in the QSEC were suggested by several research projects concerning students’ ideas about energy (Duit, 1984; Watts, 1983; Trumper, 1993; Carr & Kirkwood, 1988; Sengsook, 1997), and the questions in the physics textbook (Hobson, 1982) that was used both in Thailand and New Zealand. The questionnaire was checked by science teachers, scientists, and science educators. These experts gave suggestions to ensure that all questions were asked accurately so as to achieve the purposes for which they were designed, but some questions and choices needed to be improved. Therefore the questionnaire was piloted with Grade 9 students in schools, both in Thailand and New Zealand, in early January 2004. Piloting allowed the researcher to know the time required for students to complete the questionnaire, and how the questionnaire could be improved. The data analysis revealed that some items were confusing and so needed to be edited.

Data Collection and Analysis

The QSEC presented the students with tasks such as using the word ‘energy’ in three short sentences, giving forms of energy and reasons for energy saving, describing their understanding of the law of energy conservation, selecting given situations which could be described by the law of energy conservation, and explaining the energy transformation that takes place in hydro-generated power. The ideas in the QSEC were categorized. The New Zealand and Thai students’ ideas about energy were compared and contrasted by the percentages of the students’ framework descriptions in each category.

RESULTS AND DISCUSSION

The New Zealand and Thai students’ existing ideas of energy concepts will be discussed. The aspects of discussion include student description frameworks of energy concepts, and students’ existing ideas of the law of energy conservation, energy transformation and degradation.
Description Framework of Energy Concepts

Students were asked to use the word ‘energy’ in three short sentences. These sentences reflected the students’ understanding of energy. All of their sentences could be categorized into six frameworks of description concerned with: 1) the natural occurrence of energy in things and living things, 2) energy saving, 3) sources of energy, 4) types of energy, 5) transformation of energy, and 6) the mechanical use of energy. The details in each framework are discussed below.

First, concerning the natural occurrence of energy in things and living things, the students’ statements below illustrate their understanding and ideas:

“Energy is the most important thing for life.”
“My body uses 1000 calories of energy a day.”
“Eating food increases the energy in the human body.”
“Working out affects the burning of energy in my body.”
“Living things have energy.” (Thai students)

“My friend Rebecca got a lot of energy because she drank V.”
“We get energy by eating.”
“Drinks like V, Red Bull etc contain energy.”
“Energy is everywhere.”
“Energy is part of everyday life, humans need energy to live.” (New Zealand students)

In the category of saving energy are student sentences related to saving energy, worthy energy use, or an appreciation of the value of energy, as in these examples:

“Every one has to use energy more than necessary.”
“We should save energy because it is continually decreased.”
“Energy is a valuable and useful thing.”
“We should use energy carefully.” (Thai students)

Student sentences related to energy sources (e.g. the sun, water, and batteries) include:

“The sun’s energy is used in solar cells.”
“Power plants use water energy to generate electricity.”
“I played with my toy until the battery ran out.” (Thai students)

“Energy is a source of light.”
“Energy is a source of light can be making out of for a use of electricity.”
“An easy way of energy making is using solar power.” (New Zealand students)
In the category of types of energy, students’ sentences are related to different forms of energy. Many Thai students did not write sentences related to types of energy; they just wrote down forms of energy such as “heat”, “electricity”, and “mechanical energy”. Following are example sentences from this category:

“Energy consists of many forms.”
“I can see everything because of light energy.”
“My television consumes electrical energy.” (Thai students)

“Static electricity is a form of energy.”
“Energy comes in 2 forms, positive & negative.”
“Types of energy can be categorised under positive energy or negative energy because charge of the cells in the energy.”
“Energy as in electricity, lights etc.”
“Energy has many different forms, kinetic, gravitational, electromagnetic, and light.” (New Zealand students)

In the category of energy transformation, explain their way of thinking about energy in terms of transformation:

“Energy is never lost but changes into other energy.”
“The power plant changes water energy into electrical energy.” (Thai students)

“Energy transforming light, heat, coldness etc…."
“A push or a pull gains energy from food, water, power station etc.”
“Energy can be produced in many ways.”
“Energy cannot be destroyed or created, it just transforms into another kind of energy.”
“Energy can be changed into different types of energy.” (New Zealand students)

In the category of mechanical use of energy, students provided examples concerning the mechanical use of energy, such as:

“People use machine energy in factories.”
“Moving is mechanical energy.” (Thai students)

“The forces used when moving objects.”
“Energy makes things move.”
“I think energy is a force of something, using energy to power mechanical things.” (New Zealand students)
Table 1. Student frameworks of energy conceptions

<table>
<thead>
<tr>
<th>Framework</th>
<th>Thai students</th>
<th>% of responses</th>
<th>New Zealand students</th>
<th>% of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural occurrence</td>
<td>13</td>
<td>18.9</td>
<td>20</td>
<td>43.5</td>
</tr>
<tr>
<td>Energy saving</td>
<td>15</td>
<td>21.7</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Sources of energy</td>
<td>15</td>
<td>21.7</td>
<td>6</td>
<td>13.1</td>
</tr>
<tr>
<td>Types of energy</td>
<td>8</td>
<td>11.6</td>
<td>10</td>
<td>21.7</td>
</tr>
<tr>
<td>Energy transformation</td>
<td>8</td>
<td>11.6</td>
<td>7</td>
<td>15.2</td>
</tr>
<tr>
<td>Mechanical use of energy</td>
<td>10</td>
<td>14.5</td>
<td>3</td>
<td>6.5</td>
</tr>
<tr>
<td>Total</td>
<td>69</td>
<td>100.0</td>
<td>46</td>
<td>100.0</td>
</tr>
</tbody>
</table>

In brief, the different modes of students’ description frameworks of energy concepts are summarised in Table 1. The majority of New Zealand students wrote sentences that fall into the framework of natural occurrence, which involves existing energy in living and non-living things. This finding is consistent with Watts’s study (1983). This seems to be the most fundamental idea of energy amongst the New Zealand students. Watts (1983) argues that the existing idea of stored energy within objects stems from the Western beliefs about ‘power’. The power within things that enables them to act is often called energy. In contrast, the Thai students wrote sentences which were presented across the six frameworks. However, the two most commonly mentioned areas were sources of energy, and energy saving. This focus on sources of energy is consistent with Sengsook’s prior study (1997) which indicated fuel as a common idea of energy for Thai students. This might be generated from the use of the term fuel (petrol) in common Thai usage, to represent energy. Concerns with energy saving might be related to their experience of campaigns to save electricity and other forms of energy.

Existing Ideas of the Law of Energy Conservation

To assess their existing ideas about the law of energy conservation, the students were asked to select two from four situations which described the law of energy conservation. The other two situations represented an idea of energy saving. Table 2 reveals that approximately 90% of the Thai students selected the situations (a) and (c) which represent the idea of energy saving, while the majority of New Zealand students selected the situations (b) and (d) which represent the concept of the law of energy conservation. It seems, therefore, that New Zealand students have a better understanding of the law of energy conservation. However, when both groups of students were probed more about their understanding of the law of energy conservation, nearly all of their descriptions were presented in the frameworks of saving or preserving energy, or appreciating the value of energy, as shown in Table 3.

The New Zealand and Thai students’ descriptions of the law of energy conservation can be grouped into the following four categories: 1) saving energy sources, 2) storing up or preserving energy, 3) appreciation of the value of energy, and 4) ideas of energy transformation.
Table 2. Students’ responses about the law of energy conservation

<table>
<thead>
<tr>
<th>Choices</th>
<th>TH students</th>
<th>NZ students</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Dum (for Thai students) / Honi (for NZ students) has changed his incandescent bulbs to energy-saving fluorescent tubes. He has found them cheaper in the long run as they last longer and they are much brighter</td>
<td>19 33.9</td>
<td>7 11.9</td>
</tr>
<tr>
<td>(b) Ann touches the back of a fan. She finds that it is hot, so, she understands that input energy (electrical energy) has been transformed into kinetic energy in the fan, and heat energy in the motor.</td>
<td>0 0.0</td>
<td>18 30.5</td>
</tr>
<tr>
<td>(c) Daeng’s family switches off the lights and all electrical appliances, such as the television and computer, when no one is in the room, and before going to bed every night. Leaving them on standby mode will still use up energy.</td>
<td>30 53.6</td>
<td>18 30.5</td>
</tr>
<tr>
<td>(d) The officer of the Num-pong steam power plant (for Thai students) / the engineer at the Wairaki steam power plant (for NZ students) explains to students that the power plant uses high pressure steam at 500 °C as the force for turning the turbine. The turbine then turns the electric generator. This process provides electricity, but it is not 100 percent of the input energy. The remaining input energy is transformed into the thermal energy of the low pressure water and the heat of the turbine.</td>
<td>7 12.5</td>
<td>16 27.1</td>
</tr>
</tbody>
</table>

Total 56 100.0 59 100.0

Students gave descriptions of the law of energy conservation as saving energy sources, as in these examples:

“It means saving energy.”

“It is saving energy for use in the long run.”

“It means do not waste energy.” (Thai students)

“Saving energy for later usage.”

“Saving power when not enough is being produced in the hydro dams.”

“Conservation of energy is trying to save energy resources like water from dams, petrol etc.” (New Zealand students)

In the category of preserving energy, the law of energy conservation was perceived as storing up or preserving energy. Student responses included:

“It is like preserving energy.”

“Conservation of energy is storage and preserving energy.”
“It is storage for the next generation.” (Thai students)

“The storing and preserving of energy and sources of energy.” (New Zealand students)

In the category of the appreciation of the value of energy, students gave descriptions concerning using energy sparingly, or appreciating the value of energy, such as:

“Conservation of energy means understanding how to use energy effectively.”

“It is using energy to gain the highest advantage.” (Thai students)

“Um, well, conserving energy means you use it usefully, and only use as much as you need.”

“I think conservation of energy is the smart usage of energy and no wastage of it.”

“I think it means using our energy sources efficiently as so that we have energy for years to come.” (New Zealand students)

Only two New Zealand students responded in the category of energy transformation, for example, “energy doesn’t disappear, it just changes”. Apart from these two students, no one used this description to explain the law of conservation.

Table 3 reveals that the majority of students described the law of energy conservation in terms of saving or preserving energy, or appreciating the value of energy. The law of energy conservation states that the total energy of an isolated system always stays the same. That is, energy cannot be created or destroyed; energy can be transformed from one form to another, but the total amount of energy stays the same (Hobson, 1982). The concept of energy transformation could support student descriptions of the law of energy conservation. Only a few New Zealand students gave descriptions in this sense, while no Thai students commented on the law of energy conservation in this sense. These findings are consistent with Carr and Kirkwood’s (1988) and Trumper’s (1990) study which indicate that the law of energy conservation is understood as saving fuel or energy sources. It seems that student experiences might affect their perceptions of the concept of the law of energy conservation, because the term “conserving” is also used in everyday language. The English term “conserving” and the Thai word ‘A-nu-rak’ are used for both the law of energy

<table>
<thead>
<tr>
<th>Categories</th>
<th>Thai students</th>
<th>New Zealand students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saving of energy sources</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>Preserving energy</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>Appreciation of energy value</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Energy transformation</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 3. Student description categories of the law of energy conservation
conservation and preserving, and for storing up or saving energy. This confusion might generate readily socialized understandings, for example, the government campaigning for energy saving, where the terms of saving and conservation are interchangeable in common usage.

Existing Ideas of Energy Transformation

This section discusses student descriptions of the energy transformation that occurs in the process of a hydro power plant. Students were shown the diagram of a hydro power plant operation before being asked for their descriptions of the energy transformation process. Data analysis revealed that the students’ descriptions could be categorized into three frameworks of description, namely: 1) event, 2) one step, and 3) multi-step processes of energy transformation.

In the event framework, students described what happened in the hydro power plant, and what the product of the dam was (e.g. electricity and current). Their descriptions did not give ideas of changing forms of energy. Examples:

“Electricity is contributed to our houses.”

“The dam produces electricity.”

“Current flows from the dam to houses.”

In the one step framework, descriptions of energy transformation in the hydro power plant appear as transformation from one form of energy to another. Students’ descriptions can be grouped into two categories of changing forms of energy: category A, the changing of water energy into electrical energy, and category B, the changing of mechanical energy into electrical energy.

In the multi-step framework, students gave step by step explanations of how hydro power plant energy transforms from water or potential energy to electrical energy. Students’ descriptions can be grouped into two categories: category C involved transforming water or potential energy into mechanical energy and, then, into electrical energy. Category D showed ideas of water or potential energy transforming into mechanical energy, heat energy, and then electrical energy.

According to Table 4, the majority of Thai students held concepts of energy transformation. Approximately eighty percent of Thai students’ descriptions were concerned with energy being converted from one form to another, which can be categorized into the one step and multi-step frameworks. In contrast, the majority of New Zealand students’ descriptions were presented in the event framework. However, forty percent of the New Zealand students’ descriptions could be found in the one step and multi-step frameworks. Both groups of students preferred one step rather than multi-step descriptions. It therefore appears that the students only understand an ideal concept of energy transformation. Interestingly, there were a number of Thai students who employed a multi-step framework. Unfortunately, only one student recognized that heat spreads out, when giving the step by step description. Identifying heat as it appeared in students’ descriptions in category D may indicate that students easily understand the concept of the law of energy conservation. Recognizing that
Table 4. Students’ responses concerning energy transformation

<table>
<thead>
<tr>
<th>Framework</th>
<th>Thai students</th>
<th>New Zealand students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
</tr>
<tr>
<td>Event</td>
<td>5</td>
<td>17.9</td>
</tr>
<tr>
<td>One step – A</td>
<td>7</td>
<td>25.0</td>
</tr>
<tr>
<td>One step – B</td>
<td>6</td>
<td>21.4</td>
</tr>
<tr>
<td>Multi-step – C</td>
<td>9</td>
<td>32.1</td>
</tr>
<tr>
<td>Multi-step – D</td>
<td>1</td>
<td>3.6</td>
</tr>
<tr>
<td>Total</td>
<td>28</td>
<td>100.0</td>
</tr>
</tbody>
</table>

heat spreads out might help students make sense of why people need to save energy, even though scientific knowledge states that the total amount of energy stays the same.

Existing Ideas of Energy Degradation

The issue of confusion between energy saving and the law of energy conservation was raised to explore students’ ideas about the relationship between energy use and scientific knowledge. Students were asked why people try to save energy when scientific knowledge states that the total amount of energy is always constant. Students’ came up with various reasons. Their ideas can be grouped into six categories: 1) energy storage, 2) limited energy resources, 3) the difficulties of generating power, 4) saving money, 5) the difficulties of reusing energy and 6) the loss of energy.

In the category of energy storage, students considered energy storage for use in the future. Examples are:

“Even though we have a huge amount of energy resources, they might run out in the future.”

“…we have a conserved amount for back-up so we can still work.”

“To save our resources for the future generation.”

In the category of limited energy resources, students gave reasons concerning limited existing energy resources, for example:

“Some energy is limited.”

“Energy is limited but people are continually increased.”

“Even though we have an amount of energy resources, it might run out in the future.”

In the category of the difficulties of generating power, students considered the difficulties of the process of generating power, for example, “We do not have enough different ways of creating energy… or we are unable to create energy”.

12
In the category of saving money, students thought that energy saving is money saving and gaining profit. Examples of students’ ideas include:

“Saving electricity is saving money.”
“Saving energy helps the government to gain national profit.”
“Generating power is transforming energy for use … we have to pay…”

In the category of the difficulties of reusing energy, students gave some ideas concerned with the difficulties of reusing energy resources. For example:

“Energy will be gone when we use it and we cannot reuse it.”
“Energy is used… it cannot be generated quickly.”

In the category of the loss of energy, students were concerned with the loss of energy into another form, or into non-useful forms of energy. Energy transformation is a cause of the loss of useful forms of energy. Examples of student responses include:

“Energy changes into other forms, we cannot use energy in everyday life.”
“When we use energy it is always lost.”

According to Table 5, it appears that thirty percent of Thai students and seventy percent of New Zealand students had difficulties answering questions about energy saving, because they did not answer this question. The majority of students’ responses from both groups of students gave reasons of energy storage and limited energy resources. This indicates that students’ fundamental ideas focus on the restriction of useful energy forms. As simple idea of the second law of thermodynamic, energy degradation could be viewed as spreading out energy and it is hard to become more useful energy. Students’ reasons showed some existing ideas of energy degradation. Their ideas of the difficulties of reusing energy and the difficulties of generating power could reflect that the students are aware of the difficulty of reversing energy that is not useful into useful energy. Additionally, their ideas about the loss of

<table>
<thead>
<tr>
<th>Categories</th>
<th>Responses</th>
<th>Thai students</th>
<th>New Zealand students</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
</tr>
<tr>
<td>Energy storage</td>
<td>9</td>
<td>21.4</td>
<td>5</td>
</tr>
<tr>
<td>Limited energy sources</td>
<td>10</td>
<td>23.8</td>
<td>2</td>
</tr>
<tr>
<td>Difficulties of generating power</td>
<td>1</td>
<td>2.4</td>
<td>3</td>
</tr>
<tr>
<td>Saving money</td>
<td>4</td>
<td>9.5</td>
<td>1</td>
</tr>
<tr>
<td>Difficulties of reusing energy</td>
<td>4</td>
<td>9.5</td>
<td>0</td>
</tr>
<tr>
<td>Loss of energy</td>
<td>2</td>
<td>4.8</td>
<td>0</td>
</tr>
<tr>
<td>No reply</td>
<td>12</td>
<td>28.6</td>
<td>19</td>
</tr>
<tr>
<td>Total</td>
<td>42</td>
<td>100.0</td>
<td>30</td>
</tr>
</tbody>
</table>
energy suggest that they might be concerned with the declining usefulness of energy. Interestingly, the categories of the difficulties of reusing energy, the difficulties of generating power, and the loss of energy appear in the Thai students’ responses, although there is only a small number of such responses. However, the New Zealand students were only concerned with the difficulties of generating power.

IMPLICATIONS FOR TEACHING AND LEARNING

The fundamental New Zealand student framework of energy concepts involves the natural occurrence of energy in things and living things, but Thai students’ ideas are expressed in two modes: sources of energy and energy saving. These findings make it evident how different contexts affect students’ energy concepts. This corresponds with much research that has studied students’ energy concepts in terms of what they perceive in everyday life (Duit, 1981; Watts & Gilbert, 1983; Solomon, 1983; Brook & Diver, 1984; Lijnse, 1990; Trumper, 1990; Sengsook, 1997). Student conceptual development may involve allowing students to learn about how their existing ideas are debated and tested until there is a consensus decision within the classroom community that is similar to the scientific community (Solomon, 1983; Coll et al., 2005). This group of Thai students might begin with issues of sources of energy and energy saving. These might give ideas and knowledge about phenomena and experiences that students bring to the classroom, and might help them further understand the nature of energy.

This research shows that students have difficulty understanding the nature of energy. Both New Zealand and Thai students perceive the law of energy conservation in terms of saving or preserving energy, or the appreciation of the value of energy, rather than in the sense of the total of an isolated system which always stays the same. This corresponds with much research which indicates that students seem to understand the law of energy conservation as saving energy (Duit, 1984; Solomon, 1985; Carr & Kirkwood, 1988; Trumper, 1990). This indicates that students’ existing ideas about energy are confused by the socialization process (Solomon, 1983; Trumper, 1990). Additionally, the majority of students recognize ideal concepts of energy transformation, namely, their descriptions are mostly given in the one step energy transformation framework. There are a few descriptions of energy transformation involving the concept that energy can be converted into several forms. A small number of students expressed some ideas of energy degradation, e.g. giving reasons for energy saving, ideas about the difficulties of reusing energy, the difficulties of generating power, and the loss of energy. These findings reveal that their understanding of the law of energy conservation, energy transformation and degradation are fragmented. In order to develop students’ understanding of these energy concepts, Duit and Heaussler (1994) argue that enhancing the concept of energy spreading out would support the conceptual development of the nature of energy, because it gives reasons why a system stays the same, and reminds students to recognize energy transforming into several forms.

Besides eliminating students’ misunderstandings of the law of the conservation of energy, and developing their understanding of energy transformation, there are
other reasons to include energy degradation in the basic aspects of the energy concept. Duit and Haeussler (1994) argue that energy degradation could be used as a key energy teaching unit in the Science Technology and Society (STS) approach. The issues of degradation may motivate students to debate and test their ideas, and to develop their normative decision-making which is suitable for their context. For example, based on Thai students’ existing ideas of energy degradation, the STS energy unit containing issues of the price of petrol and energy use, and generating power and environmental damage, might be provided for this group of Thai students.

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REFERENCES

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INTRODUCTION

Heat, like many other scientific concepts, is abstract, counterintuitive and thus difficult for students to understand. As a noun, it is frequently used in everyday life, but its meanings may, however, vary from one situation to another. In the Chinese language, the word for heat, Re, used as a noun, is a completely scientific term. In everyday life, Re means “hot”, “heated” or “to heat”, and students do not start to learn Re as a noun - heat – until in school science. It is thus little wonder that many students, and even adults, encounter difficulties in understanding the scientific concept of heat alongside its everyday multiple uses. Furthermore, heat is confusing and controversial in its own scientific meaning, as illustrated in the history of science. Early scientists for a long time conceived of heat as a basic quality of a body, and later on as a kind of substance, a material fluid, or in terms of an ethereal wave. It was as late as the 19th century that the modern concept of heat became accepted.

Bearing this in mind, we should not be too surprised at the difficulties students experience while learning the concepts centered on heat.

Research has provided abundant evidence that students come into the science classroom with their own knowledge, which is often different from the intended scientific information, yet makes sense to the students themselves. (Duit (2006) has conducted an extensive review of the literature in this area.) This kind of knowledge is often coherent to everyday experience, and has its own structure, and therefore is robust to change. In the last decades, research in science education had focused on the ways in which students’ preconceptions could be “changed” to the scientific form. Yet recent years have witnessed a shift of the emphasis from “conceptual change” to “conceptual recognition and appreciation” (where conceptual change is still consequently involved). Precisely speaking, the general goal of science instruction is currently directed at assisting students to recognise and appreciate their personal knowledge for its functional appropriateness in certain contexts, and to further distinguish it from the scientific knowledge intended in science instruction.

These different representations of knowledge involved in science teaching and learning should therefore be identified and clarified. Especially important is to specify the underlying meanings and relations of these representations in order to assist students in understanding their own and others’ ideas. The study presented in
this paper is focused on the students, with the goal to re-examine the representations of the basic thermal concepts in science instruction.

STUDENTS’ IDEAS ABOUT HEAT

Literature Review

Previous research has provided evidence that students hold many intuitive ideas about heat and temperature (Clough & Driver, 1985; Erickson, 1979; Erickson & Tiberghien, 1985; Rogan, 1988; Tiberghien, 1980), and that everyday experiences play an essential role in forming these ideas. A summary of the ideas as such is listed in Table 1.

Everyday, children are exposed to the colloquial term “heat” as a noun, and its related forms as a verb, adverb, and adjective, and these multiple uses may lead to confusion (Erickson & Tiberghien, 1985; Romer, 2001; Tiberghien, 1980). Typically, children hold substance-based conceptions, such as heat as a substance (Albert, 1978) or a substantive fluid (Erickson, 1979, 1980). This is predicted from an ontological perspective (Chi, 2000; Chi, 1992).

Intuitive ideas do not change easily. Research shows that even after some years of instruction, students still have difficulties differentiating between heat and temperature when they explain thermal phenomena (Kesidou & Duit, 1993). Their idea of temperature as a measure of heat appears to be particularly resistant to change.

Studies of students’ concepts about heat have been generally focused on primary and middle school students. It is argued that secondary students do not exhibit their

<table>
<thead>
<tr>
<th>Students’ ideas</th>
<th>Heat</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat</td>
<td>Heat as a substance, like air or steam (Albert, 1978; Erickson, 1979).</td>
<td>A measure of the mixture of heat and cold inside an object (Erickson, 1979).</td>
</tr>
<tr>
<td></td>
<td>Heat as a substantial fluid (Erickson, 1979, 1980).</td>
<td>Temperature as a property of material. (Erickson &amp; Tiberghien, 1985).</td>
</tr>
<tr>
<td></td>
<td>Temperature is subject to the size of the object and the amount of stuff present. (Erickson, 1979).</td>
<td>Temperature is subject to the size of the object and the amount of stuff present. (Erickson, 1979).</td>
</tr>
<tr>
<td></td>
<td>Temperature measures or quantifies heat (Kesidou &amp; Duit, 1993).</td>
<td>Temperature measures or quantifies heat (Kesidou &amp; Duit, 1993).</td>
</tr>
<tr>
<td></td>
<td>Temperature has a similar meaning to heat (Erickson 1979; Kesidou &amp; Duit, 1993; Wiser &amp; Amin 2001).</td>
<td></td>
</tr>
<tr>
<td>Heat and material</td>
<td>Color, thickness and hardness are associated with conductivities (Clough &amp; Driver, 1985).</td>
<td>The speed of the heat movement explains different conductivities. (Clough &amp; Driver, 1985; Tiberghien, 1980).</td>
</tr>
<tr>
<td></td>
<td>The speed of the heat movement explains different conductivities. (Clough &amp; Driver, 1985; Tiberghien, 1980).</td>
<td></td>
</tr>
<tr>
<td>Heat and coldness</td>
<td>“Coldness” as a substance (Clough &amp; Driver, 1985).</td>
<td>Heat and cold/coldness as two opposite substances (Erickson, 1979, 1980).</td>
</tr>
</tbody>
</table>
alternative conceptions in an obvious manner for they “are relatively quick at learning verbal labels and scientific-sounding phrases, yet the classroom interaction is normally not long enough to reveal what kind of understanding lies behind such words or phrases” (Clough and Driver, 1985, p. 181). Also, there seems to be a lack of variety of testing instruments for diagnosing students’ understanding of a specified concept or theory, with interviewing being commonly used in these studies. The study is thus intended to examine, by means of an alternative testing instrument, secondary students’ understanding of the basic thermal concepts such as heat, temperature and thermal equilibrium, which they have already learnt through formal instruction.

Methodology

Participants in the investigation were 252 secondary students (Grades 10–12; 15–18 years old) selected from two schools in Taiwan. Before the investigation, a pilot study using an open-ended questionnaire was carried out to elicit students’ general accounts of the nature of heat and temperature. Its purpose was to revise the questionnaire and develop items for its multiple choice questions using students’ comments. 134 students from another school participated in the pilot study, responding in a written form to several open-ended questions, such as “(After referring to obvious thermal phenomena) What is heat?” and “Why does metal generally feel colder than wood?” Students were asked to explain their ideas as clearly as possible, and were encouraged to do so by means of drawings.

A testing instrument with multiple choice questions was thus developed based on the results of the pilot study. The questions, which amount to nine in all, concern basic thermal problems and phenomena to be explained or predicted. Only Question 9, for its explanatory nature, remains as an open question, whereas all other questions contain items to choose. Questions 1, 2 and 3 require the student to give a general account of heat, heat transfer and the function of a thermometer, whereas the rest of the questions are contextual, consisting of a problem or phenomenon. To give a scientifically correct answer (by choosing from the items or providing an alternative statement) requires a basic understanding of thermal knowledge. In this revised questionnaire, each question, apart from Question 9, has five items, four of which are opinions presented by four imaginary figures, whereas the other allows the student to express his (her) own opinion when (s)he disagrees with all of the stated opinions.

An exemplar question and its response items are as follows:

(Question 8) Suppose a metal plate, some flour, and a cup of water are kept at room temperature for a while and then put into a freezer at the temperature of -5°C. What would happen to them?

– Student A: “They will keep releasing heat until they contain the same amount of heat.”
– Student B: “Their temperature will all decrease and reach -5°C at the end.”
– Student C: “Some things cannot reach that low temperature. They will all become very cold, but at the end the metal should have the lowest temperature, and then the water, which turns to ice, and finally the flour.”
– Student D: “I also think that their temperature will all drop, but the final temperature of the ice should be the lowest, because it should feel the coldest.”
– None of them are correct. My idea is__________

In order to obtain more personal views, Question 9 requires students to explain in their own words the melting process of ice cream, including why it occurs, and the difference between the particles of the already melted and the still solid parts of the ice cream.

**Results**

*Pilot study.* The pilot study revealed a similar pattern of students’ concepts about heat to that found in the previous studies. A considerable number of students related heat to hotness, commenting, for instance, that “Heat is, when two things have different temperatures, the one which has the higher temperature.” and “Heat is a kind of energy and it feels hot.” Some students seemed to confuse heat with temperature. Their statements include “Heat is the degree of hotness and coldness”, “Heat is a kind of temperature, which tends to be higher.” and “Heat is what one feels about the environment in terms of hotness and coldness. We use temperature to indicate it.” It is also evident that they often believe heat to be the amount of energy that a body has. One student cited, for example, “Heat moves from what has higher heat energy to lower.” It also occurred, though rather exceptionally, that the student categorised heat into material. An exemplar citation is “It is a kind of material which has energy but no form.”

Data collected in the pilot study indicated that even after repetitive formal instruction on the fundamental science of heat (as part of the primary, middle, and secondary science curriculum) students still have difficulties explaining basic thermal terms and phenomena in a coherent manner. They often unconsciously switch between the learnt scientific knowledge and the common sense ideas according to the question to be answered. It seems that while responding to an open question students tend to first look for explanations based on their everyday experience instead of drawing upon what they have learnt. The observation, for example, of sun and fire is so influential that the student may easily define heat as “the kind of energy which is released from a body.” It should be noted that few students automatically mentioned particles or the particle model when explaining the concepts and phenomena of heat. As pointed out, students gave their responses primarily based on everyday experience, probably due to the fact that there was no item to choose from and thus no hint to recall their learnt knowledge, and therefore the particle model was one of the last things to emerge in their thinking, since it is anything but intuitive.

**Main Study**

*Nature of heat.* The students participating in the main test exhibited a familiarity with the basic thermal terms such as heat (energy), temperature, heat transfer, thermal equilibrium, and specific heat. Few students related heat directly to substance
WHAT IS THE THING WE CALL HEAT

(Table 2.1, the first item). The statement that heat is a kind of energy is easy for them to recall as it is repetitively taught. It seems that, however, in describing the movement of heat they tend to visualize it in a corporeal manner, i.e., heat transfer is often depicted as if it is an actual continuous transmission (Table 2, the third item, Table 3).

<table>
<thead>
<tr>
<th>Table 2. Students’ responses to Question 1: What is heat?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 10 (n=91)</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Heat is a substance. It has no form and no colour. Something is hotter when it has more of the heat substance.</td>
</tr>
<tr>
<td>It is a kind energy that can make temperature rise. An object with more heat must be hotter.</td>
</tr>
<tr>
<td>Heat is a kind of “released” energy, for example, fire can release this energy, but ice not.</td>
</tr>
<tr>
<td>Heat should be a quality of an object, that is, its degree of hotness or coldness. It can be illustrated through temperature.</td>
</tr>
<tr>
<td>None of them is correct. My idea is_________________</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. Students’ responses to question 6: What happens to the particles inside a metal stick heated at one end?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 10 (n=91)</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>The number of particles containing heat increases.</td>
</tr>
<tr>
<td>Particles speed up and the distances among them increase.</td>
</tr>
<tr>
<td>Particles move away carrying heat which flows in from the source.</td>
</tr>
<tr>
<td>Particles near the source take in heat and pass it onto the neighbouring particles in a similar way to the radiation of the sun.</td>
</tr>
<tr>
<td>None of them is correct. My idea is_________________</td>
</tr>
<tr>
<td>No response.</td>
</tr>
</tbody>
</table>
Figure 1 shows a sketch by a 12th-grader where a metal is heated at one end and heat goes around the metal like an “infinite” circuit.

As mentioned previously, the students frequently used the scientific terms such as thermal equilibrium, temperature, heat transfer, specific heat and even latent heat while explaining concepts and phenomena in their answers. However, similar to the results of the pilot study, their accounts revealed confusion between heat and temperature, heat and thermal energy, and moreover, exhibited a vague understanding of energy as an essential character of heat.

Temperature is often thought to be the indicator of how much heat an object contains. According to one 10th-grader, if one of the two identical objects has a higher temperature than the other, it consequently has more heat. Another 10th-grader, after stating that heat is a kind of energy, pointed out that “It is temperature, which can reflect the change of the amount of this energy.” Table 2 also shows that approximately one out of three students considered heat as “the degree of hotness or coldness” (the fourth item).

The majority of the students spoke of heat as a “possessed” property similar to thermal energy. “Heat in a body” is often, directly or indirectly, present in their responses. For example, a student responding to the question of what happens to a metal and a wooden stick if being placed under the midday sun for a while, wrote “They will reach the same temperature, but they will not have the same amount of heat [at the end].” Table 4 (the first item) shows that a number of students think of heat as an internal property, which can be calculated using a simple formula.

It is also noticeable that two ideas, heat transfer as a result of different temperatures, and heat radiation simply caused by an object’s temperature, seem to be incongruous for the students, and consequently led to some misconceptions. While explaining heat transfer, a student wrote “No matter what temperature (a body has), as long as it’s above 0 K, heat is sent out, and it goes from the higher amount of heat to the lower amount of heat.” It is understandable that to put “heat goes from the higher temperature to the lower temperature” will likely cause confusion, as it appears to be in contradiction to the first statement about heat radiation.
Table 4. Students’ responses to question 4: What can be concluded based on information of two cups of water: (A) 200 grams, 25°C; (B) 50 grams, 90°C?

<table>
<thead>
<tr>
<th></th>
<th>Grade 10 (n=91)</th>
<th>Grade 11 (n=80)</th>
<th>Grade 12 (n=81)</th>
<th>Total (n=252)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A has 5000 cal of heat, while B has 4500.</td>
<td>28 (31%)</td>
<td>16 (20%)</td>
<td>12 (15%)</td>
<td>56 (22%)</td>
</tr>
<tr>
<td>B has a higher temperature, so B should have more heat than A.</td>
<td>0 (0%)</td>
<td>5 (6%)</td>
<td>5 (6%)</td>
<td>10 (4%)</td>
</tr>
<tr>
<td>If we pour one cup of water into another, a final state, thermal equilibrium, will be reached where the amount of heat should be between 4500 and 5000 cal.</td>
<td>19 (21%)</td>
<td>11 (14%)</td>
<td>11 (14%)</td>
<td>41 (16%)</td>
</tr>
<tr>
<td>If two cups of water are mixed, we can predict that the temperature when thermal equilibrium is reached will be between 25°C and 90°C.</td>
<td>72 (79%)</td>
<td>68 (85%)</td>
<td>59 (73%)</td>
<td>199 (79%)</td>
</tr>
<tr>
<td>None of them is correct. My idea is __________</td>
<td>4 (4%)</td>
<td>3 (4%)</td>
<td>5 (6%)</td>
<td>12 (5%)</td>
</tr>
<tr>
<td>No response.</td>
<td>1 (1%)</td>
<td>0 (0%)</td>
<td>4 (5%)</td>
<td>5 (2%)</td>
</tr>
</tbody>
</table>

Heat and thermal equilibrium. Thermal equilibrium is one of the core concepts in school thermal science and thus seems to be a familiar term for the students. Most of the students know that all entities in a thermal system would approach thermal equilibrium. However, students’ responses revealed a somewhat distorted scientific concept of thermal equilibrium. Even if the student can recite the scientific definition of thermal equilibrium, they may not be able to apply it to real problems. Responding to Question 9, the students frequently stated that ice melts because of the drive to approach thermal equilibrium with the environment. Nevertheless, in a more unusual situation, the problem emerges. Most obvious is the fact that many of them turned to an intuitive answer when the situation was familiar but contained a potential conflict between a scientific explanation and a common sense idea.

Table 5 (the first item) shows that many students have the scientifically correct idea of heat transfer as a result of the difference in temperature. However, the final state of this transfer, thermal equilibrium, is not understood. A considerable number of students believe that the metal stick would be eventually hotter than the wood if they are placed in the sun together, as seen in Table 6 (the first and third items), and the flour would not become as cold as the ice and the metal in the freezer, as illustrated in Table 7 (the third and fourth items).
Table 5. Students’ responses to question 2: Under what condition(s) does heat transfer between two bodies?

<table>
<thead>
<tr>
<th>Condition</th>
<th>Grade 10 (n=91)</th>
<th>Grade 11 (n=80)</th>
<th>Grade 12 (n=81)</th>
<th>Total (n=252)</th>
</tr>
</thead>
<tbody>
<tr>
<td>When there is a difference in temperature. Heat transfers from higher to lower temperatures.</td>
<td>69 (76%)</td>
<td>40 (50%)</td>
<td>42 (52%)</td>
<td>151 (60%)</td>
</tr>
<tr>
<td>When there is a difference in heat contained by the objects. Heat moves from a place of more heat to that of less heat.</td>
<td>17 (19%)</td>
<td>31 (39%)</td>
<td>17 (21%)</td>
<td>65 (26%)</td>
</tr>
<tr>
<td>It depends on the material: Some materials take in heat more easily, while others release heat more easily. Thus, the latter tends to give out heat to the former.</td>
<td>6 (7%)</td>
<td>10 (13%)</td>
<td>5 (6%)</td>
<td>21 (8%)</td>
</tr>
<tr>
<td>It depends on the size, mass, state and so on of the substances. So we cannot make a general conclusion.</td>
<td>16 (18%)</td>
<td>20 (25%)</td>
<td>20 (25%)</td>
<td>56 (22%)</td>
</tr>
<tr>
<td>None of them is correct. My idea is_________________________</td>
<td>4 (4%)</td>
<td>5 (6%)</td>
<td>6 (7%)</td>
<td>15 (6%)</td>
</tr>
<tr>
<td>No response.</td>
<td>1 (1%)</td>
<td>1 (0%)</td>
<td>1 (1%)</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Students’ responses to question 7: What would happen to a metal and a wooden stick moved from inside to outside under the midday sun?

<table>
<thead>
<tr>
<th>Condition</th>
<th>Grade 10 (n=91)</th>
<th>Grade 11 (n=80)</th>
<th>Grade 12 (n=81)</th>
<th>Total (n=252)</th>
</tr>
</thead>
<tbody>
<tr>
<td>The temperature of the metal stick will rise, but that of the wooden stick may not rise, or perhaps may only rise a little bit.</td>
<td>55 (60%)</td>
<td>42 (53%)</td>
<td>37 (46%)</td>
<td>134 (53%)</td>
</tr>
<tr>
<td>Their temperatures will both rise, and eventually reach the same degree.</td>
<td>15 (16%)</td>
<td>21 (26%)</td>
<td>20 (25%)</td>
<td>56 (22%)</td>
</tr>
<tr>
<td>Wood can maintain the warmth better, so at the end the wooden stick should have a higher temperature than the metal one.</td>
<td>3 (3%)</td>
<td>3 (4%)</td>
<td>3 (4%)</td>
<td>9 (4%)</td>
</tr>
<tr>
<td>Both will have their temperature increased, but the metal stick will possess more heat than the other.</td>
<td>7 (8%)</td>
<td>8 (10%)</td>
<td>9 (11%)</td>
<td>24 (10%)</td>
</tr>
<tr>
<td>None of them is correct. My idea is_________________________</td>
<td>16 (18%)</td>
<td>12 (15%)</td>
<td>14 (17%)</td>
<td>42 (17%)</td>
</tr>
<tr>
<td>No response.</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>1 (1%)</td>
<td>1 (0%)</td>
</tr>
</tbody>
</table>
Table 7. Students’ responses to question 8: What would happen to a metal plate, some flour and a cup of water put into a freezer at -5 °C?

<table>
<thead>
<tr>
<th>Response</th>
<th>Grade 10 (n=91)</th>
<th>Grade 11 (n=80)</th>
<th>Grade 12 (n=81)</th>
<th>Total (n=252)</th>
</tr>
</thead>
<tbody>
<tr>
<td>They will keep releasing heat until they contain the same amount of heat.</td>
<td>9 (10%)</td>
<td>12 (15%)</td>
<td>7 (9%)</td>
<td>28 (11%)</td>
</tr>
<tr>
<td>The temperature of all of them will decrease and reach -5 °C at the end.</td>
<td>46 (51%)</td>
<td>28 (35%)</td>
<td>34 (42%)</td>
<td>108 (43%)</td>
</tr>
<tr>
<td>Some things cannot reach that low a temperature. Although they will all become very cold, at the end the metal will have the lowest temperature, and then the water, which turns to ice, and finally the flour.</td>
<td>36 (40%)</td>
<td>40 (50%)</td>
<td>31 (38%)</td>
<td>107 (42%)</td>
</tr>
<tr>
<td>The final temperature of the ice should be the lowest, because it should feel the coldest.</td>
<td>4 (4%)</td>
<td>3 (4%)</td>
<td>0 (0%)</td>
<td>7 (3%)</td>
</tr>
<tr>
<td>None of them is correct. My idea is ________________</td>
<td>4 (4%)</td>
<td>7 (9%)</td>
<td>7 (9%)</td>
<td>18 (7%)</td>
</tr>
<tr>
<td>No response.</td>
<td>1 (1%)</td>
<td>0 (0%)</td>
<td>4 (5%)</td>
<td>4 (2%)</td>
</tr>
</tbody>
</table>

Heat and the particle model. As revealed in the pilot study, few students automatically mentioned the particle model when asked to explain heat and its motion. The reference to particles and the particle model occurred in the responses only when required. There also seems to be a tendency that the students describe particles based on the object’s macroscopic quality. In explaining differences between particles in ice and in water (Question 9), a popular answer was “density”. The fact that ice is obviously more “condensed” than water appears to have a strong impact on the student’s understanding of the particles in these two materials. A comment from a 10th-grader also illustrated such a macroscopic-oriented microscopic view: Particles in water are “looser and not fixed”, whereas those in ice “have the same distance between one another and have a fixed pattern”.

Restructuring Concepts of Heat

Scientific Explanations

In science, it is wrong to speak of “heat in a body”, as heat is defined as a form of energy transferred between systems. Heat is thus an extrinsic quality. Suppose a cup of water is sitting on the counter. As a whole, the cup is at rest, but internally there is lots of action – all the molecules are in motion. It therefore has “molecular kinetic energy” which is known as “internal energy”. Because this energy is associated with the temperature of the water, it is also called “thermal energy”.

WHAT IS THE THING WE CALL HEAT
Heat is the flow of this energy from one system to another, through solid and fluid media by conduction, through fluid media by convection, and through empty space by radiation. This flow results from a difference in temperature or a change in phase.

Temperature refers to how hot or cold an object is. Thus heat only flows from high temperatures to low temperatures. At the secondary school level, students are exposed to the explanation of heat in terms of the particle model, which suggests that all matter is made up of tiny particles too small to be seen. According to this model, these particles are always moving - they have energy. With an increase in temperature, the particles move faster as they gain kinetic energy. Thus, when something is really hot, the particles inside it are wiggling around a lot. And the colder it is, the less the particles wiggle. According to this theory, temperature indicates the average energy (speed) of the particles in motion in a substance. It is therefore closely associated with thermal energy: Temperature represents the intensity of the warmth, whereas thermal energy the totality (von Baeyer, 1999).

While heat is explained as a form of energy, energy is another tricky term. One cannot understand heat correctly without grasping the meaning of energy. What is energy in a scientific sense? It is not a substance. It cannot be seen or weighed, and it cannot take up space. Energy is a condition or quality that a substance has. Energy is a property or quality of an object or substance that gives it the ability to move, do work or cause change.

Instructional Reformation

The results of this study revealed a feature of discrepant knowledge in the students’ representations. Although students at secondary level seem to be familiar with a number of thermal terms, their understanding of these concepts remains at a superficial level. The confusion between concepts, such as heat, thermal energy and temperature, illustrated the problem that students understand neither the underlying principles of these concepts nor their relations. They seem to deal with a number of facts and ideas without an effective conceptual map to locate and relate them. As a result, their knowledge is fragmented and shallow (Marton, Hounsell, & Entwistle, 1984). This should call for a re-examination of the instructional subject matter towards a more analytic and coherent representation of the knowledge, and efforts to develop strategies for assisting students in building conceptual maps or models that locate and relate the learnt concepts and phenomena, as well as their personal knowledge.

To take heat and thermal energy as an example, students need to recognize their fundamental difference - the former is an extrinsic quality, whereas the latter is intrinsic. Suppose we have a cup of hot water at hand. Common sense tells us that it will cool down naturally. It seems thus natural to assume that something inside the cup is being released. The crucial point is that thermal energy is this “something” inside the cup, whereas the part of it being released is called heat. Therefore, the manifestation of heat is present in virtually all thermal events, when one can “feel” a change. In contrast, thermal energy is something internal and in nature is associated with motions of atoms and molecules. It is worth recommending using examples from the everyday world to illustrate the intended knowledge in a way that special
attention is paid to the crucial points through which students can discern one concept from another, and consequently recognize their relations.

It should be of significance to explain thermal concepts in reference to the microscopic and macroscopic levels of representation. Students often get confused when we speak of heat in terms of particle motion and in terms of the moving energy from hotter substances to colder ones without explicating the microscopic and macroscopic perspectives from which the different explanations are derived.

As Wiser and Amin (2001) have suggested, to foster students’ conceptual change regarding heat, we need to “encourage students explicitly to differentiate between the scientific and everyday views and then integrate them into a coherent account including both views” (2001, p. 353). In addition, instruction can involve their analogies to the historical development of thermal theories (Cotignola, Bordogna, Punte, & Cappannini, 2002); thereby students are provided with the opportunity to project their ideas onto the historical ones and to understand these ideas and the perspectives from which they are generated.

NOTES

1 In all the tables illustrated in the chapter, the sum of the responses does not equal the number of students in each grade because of the multiple choices. For the same reason and rounding, the total percentage in each grade does not amount to 100. The rates are calculated by dividing the number of students providing the response by the number of students taking part in responding, and then rounding to the nearest one.

REFERENCES


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