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YEAR 3 STUDENTS' CONCEPTIONS OF HEAT TRANSFER

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Many children and adults have problems differentiating between heat and temperature. As a consequence, intuitions developed about the transfer of heat and other thermal concepts do not align with scientific explanations of the phenomena. These intuitions are formed as alternative conceptions, which are resistant to change and persist as children progress through school. In order to develop teaching interventions that challenge children's thinking it is necessary to determine the potential alternative conceptions developed early in life. Embedded within the context of a STEM research project, the study reported in this paper explored Year 3 students' conceptions about heat transfer and the properties of insulation after they had worked through an experiment that required them to collect data to determine the effect of insulation on the transfer of heat. The students were interviewed and the transcripts were interrogated to identify the instances when the students demonstrated their conceptions of thermal concepts. The aim was to determine the way in which the students related their conceptions of heat transfer and insulating properties of material to the context of the experiment and to every day experiences. Excerpts from the student interviews are used to illustrate the range of understanding expressed by the students.

Introduction

Research into student learning in science has focused on the understandings of the world that students bring to the classroom, knowing those constructions of scientific concepts will have an impact on learning and thereby, influence pedagogical practices (Tytler, 2002). The role of the teacher is to activate students' prior learning, make connections to real-world contexts, and facilitate cognitive development (Fitzgerald & Smith, 2016). For substantive learning to occur, knowledge of the conceptions students bring to the learning experience can support the teacher to design learning experiences that challenge those ideas and support development of conceptions that align with scientific explanations considered acceptable. Preconceived ideas can, and often do, include explanations that are scientifically inaccurate or only partially correct. Although it seems logical to refer to these ideas as misconceptions, Keeley (2012) observes that this term can lead to complacency about how these problematic ideas should be treated by teachers. Tytler (2002) notes that the term "misconception" implies the students' ideas are simply wrong and need to be corrected. The term "alternative conceptions" has gained favour in research, and is used in this paper, as it describes students' active construction of an idea and reminds teachers that such conceptions are complex. Rather than simply being corrected, alternative conceptions need to be challenged strategically to assist learners to develop more scientific explanations of their experiences.

Even in their earliest years, students experience the behavior of heat. The concept of heat is, however, difficult to explain due to the various ways in which heat is described (Sozbilir, 2003). In order to understand the scientific explanation of heat, a conceptual understanding of energy is needed. Heat is defined for science teachers as "the transfer of internal energy from one substance to another in the process of heating or cooling" (Hubber & Jobling, 2015, p. 123). The "internal

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energy" of a substance is the sum of the kinetic energy, or movement, of its particles and the potential, or stored, energy of its chemical bonds (Hubber & Jobling). A distinction is made here between heat and energy as it is scientifically incorrect to describe heat as a form of energy. Scientific convention has a preference for the term "thermal energy" to refer specifically to the energy involved in heat transfer. Thermal energy is the kinetic energy of an object or system that can be measured. The scientific conceptions of heat that can be expected to be understood by primary children are much simpler and generally refer to observations of what heat does, rather than what it is. In keeping with the simpler explanations given by young children, in this paper, thermal energy is referred to as the transfer of heat, which can be determined by measuring the change in temperature of a substance. This facilitates distinguishing between scientific conceptions of heat and alternative conceptions, particularly since young students are not likely to use the word "energy" in scientifically acceptable ways without previous instruction. Thermal insulation is a property of materials that reduces the transfer of heat between objects and substances. The aim of this study is to identify Year 3 students' conceptions of heat transfer and the role of thermal insulation.

In recent times, there has been an emphasis on providing Science, Technology, Engineering and Mathematics (STEM) learning experiences in schools to nurture students' interest in science and influence their career choices (Office of the Chief Scientist [OCS], 2013). Those experiences are likely to include hands-on activities that require students to make decisions and draw conclusions based on their experiences (e.g., Ward, Lyden, Fitzallen, & Leon de la Barra, 2015; Watson & English, 2015). It is therefore, important to explore if those sort of learning experiences offer different insights into student thinking and reasoning than those gleaned from student surveys, which are often dominated by multiple choice questions.

This paper explores young students' conceptions of the nature of heat transfer and the influence of thermal insulation in the heat transfer process. It reports on a classroom investigation set within a STEM learning context, which adopted an inquiry-led teaching approach to explore Year 3 students' understanding. It evidences the way in which students' express conceptions, scientific and alternative, formed from their experience of conducting a scientific experiment.

Students' Understanding of Heat Transfer

Research on young students' understanding of heat transfer is limited. It is mostly based on students' responses to survey-style questions (e.g., Erikson, 1979; Paik, Cho, & Go, 2007; Shayer & Wylam, 1981), which do not explore how students express, form, and make sense of conceptions within authentic learning contexts. A review of the literature on students' misconceptions of heat and temperature cites studies that were undertaken from the late 1970s (Sozbilir, 2003). Sozbilir documents the alternative conceptions for students from the age of six through to adults at the tertiary level and beyond. Although comprehensive in the number of alternative conceptions identified, there are only one or two research studies cited for each of the five age groups listed. Yeo and Zadnik (2001) also compiled a list of alternative conceptions that is similar to the one compiled by Sozbilir but they did not specify from which studies the various conceptions were sourced. Their list, however, is useful because it is sorted into four categories:

A: Students' conceptions of heat.
B: Students' conceptions of temperature.
C: Students' conceptions about heat transfer and temperature change. and
D: Students' conceptions about thermal properties of materials.

The studies most relevant to Year 3 students were carried out by Erikson (1979); Paik et al. (2007); and Rosebery, Ogonowski, DiSchino, and Warren (2010). Erikson worked with students 6-12 years of age. He conducted interviews with the students after they had observed four

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heat experiments. The alternative conceptions he identified were: hot heat and cold heat are different; heat is like a substance that moves around, heat is a form of energy, and temperature of an object changes as the size of the object changes. Similar results were reported by Paik et al., who worked with students aged 4-11 years. They also conducted interviews. In that study the researchers found the students did not distinguish between heat and temperature, described heat as an object, and the size of an object determines its temperature. Rosebery et al. worked with students 9-11 years of age. Their research focused on developing students' understanding of the particle model in relation to heat and heat transfer. It was a classroom-based study that extended over a three-month period. Relevant to the current study are the outcomes from an incident that occurred 4 weeks after the project started. During a lesson, the class was evacuated for a fire drill, which resulted in the students standing outside without their jackets. This fortuitous event led to a conversation about heat loss and insulation. The researchers reported that the students described heat as something that was able to flow from one object to another, and it was possible to stop the flow of heat with insulation, in this instance, a coat. The ability to relate the ideas about heat and insulation to their experiences revealed ideas not expressed previously.

Research Approach

The study reported in this paper is part of a larger research project carried out within an Australian Research Council Discovery Project, "Data Modelling: Enhancing STEM in the Primary Curriculum" (English, Watson, & Fitzallen, 2015). The program of research is longitudinal in nature and involves tracking two cohorts of students as they progress from Year 3 to Year 6. The research adopts a pragmatic approach (Mackenzie & Knipe, 2006) that utilises both qualitative and quantitative data collection strategies (Creswell, 2013) to identify, track, and assess students' learning with a focus on inquiry processes, informal inferential reasoning, representational skills, and STEM-based conceptual development. The project includes activities that focus on the steps of a complete statistical investigation (Franklin et al., 2007) set within STEM contexts.

Research Setting

The study was conducted with one cohort of students from the larger research project. It took place in two Year 3 classrooms at a Tasmanian urban co-educational catholic school and involved 53 students. The study took place over two, non-consecutive days (one day per class). The regular classroom teacher for each class directed a student investigation developed by the research team in collaboration with the teachers, which involved trialing the activities in the investigation before it was implemented in the classroom. Of the 53 students, four students did not give consent for their data to be used for research purposes. Although those students still completed the investigation with the rest of their class, no data generated by them were collected or analysed.

The student investigation entitled "The Heat Is On!", was designed to support students to explore the thermal insulation capacity of materials in the transfer of heat, reinforce notions of variation specifically related to heat loss over time, engage students in a complete statistical investigation, and develop students' skills in using instruments to measure temperature. The questions posed were "How does temperature vary when something gets hotter or colder?" and "What is the effect of different materials on how the temperature varies?" The investigation addressed outcomes from the *Australian Curriculum: Science* (Australian Curriculum, Assessment and Reporting Authority [ACARA], 2015) related to Science Inquiry Skills in general, and content specifically related to "Heat can be produced in many ways and can move from one object to another (ACSSU049)." The aim was to give students the opportunity to identify changes that occur in everyday situations due to heating and cooling, and recognise that the effects of heat can be measured using a thermometer. Also addressed were outcomes from the *Australian Curriculum: Technologies,* Design and

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Technologies Knowledge and Understanding strand, specifically, "Investigate the suitability of materials, systems, components, tools and equipment for a range of purposes (ACTDEK013)" in relation to thermal insulation. The data modelling in the investigation resulted in the visual representation of the data collected, which was analysed to summarise the changes observed and to draw conclusions about the overall trends, and the uncertainty arising from the variation in the data. These tasks addressed outcomes from the *Australian Curriculum: Mathematics* (ACMSP096).

The student investigation involved the students working in groups of three to record the temperature of water in two plastic cups, one insulated with a polystyrene cup (see Figure 1), over a period of 30 minutes. The students read and recorded the temperature of the water in the two cups, which contained the same volume of water at the same starting temperature ($\approx 40^0$C). The temperature was recorded at 5-minute intervals. After the first 10 minutes, ice water was added to the tray in which the cups were sitting. The temperature of the ice water was also measured at each subsequent 5-minute interval. Students recorded the temperatures in a table and then transposed the data to their Thermometer Worksheet using coloured pens to differentiate the three temperature readings—red for the insulated cup, blue for the non-insulated cup, and black for the ice water—to construct a graph. The Thermometer Worksheet was comprised of a series of thermometer images that collectively formed an unconventional graph-type. The purpose of using the stylized graph was to provide a cognitive bridge between the act of measuring the temperature and the process of modelling that data in a graphical representation. The thermometer images in the graph assisted in conserving the context of the investigation in the data representation. An example of a completed Thermometer Worksheet is in Figure 2. It was generated during the trialing of the investigation.

Figure 1. Equipment required for the investigation.

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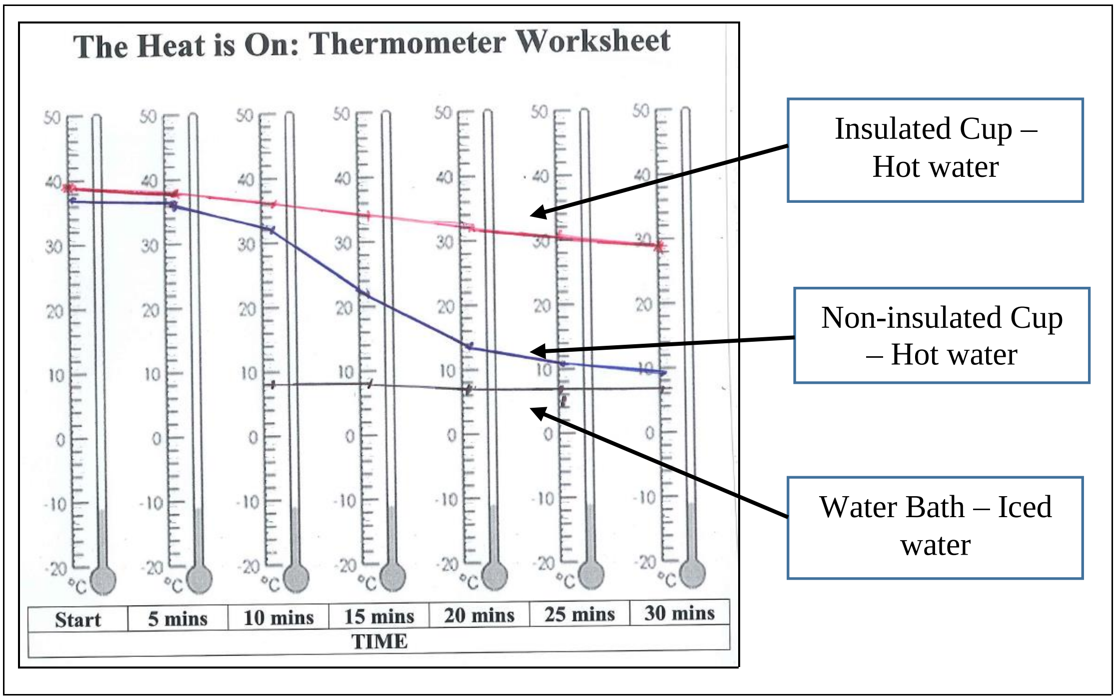

Figure 2. Example of a completed Thermometer Worksheet.

Students also answered brief questions in their workbooks throughout the investigation. The purpose was twofold. First, the questions in the workbook were posed to stimulate students thinking. Second, the workbooks provide documentary evidence of students thinking and ideas. On completion of the experiment the data collected by each group contributed to the construction of a class plot (see Figure 3), which was followed by a class discussion to identify the variation in the class data. In their workbooks, students described the shapes and patterns in the plot, gave reasons for the variation in the data, suggested what caused the variation, and commented on the uncertainty of the class results. Predictions were also made of the temperature of the water in the cups and the tray after three hours. The research outcomes from the students' written work are not a focus of this paper. The results will be reported elsewhere. The data reported in this paper were generated from student interviews conducted after the heat transfer investigation was completed.

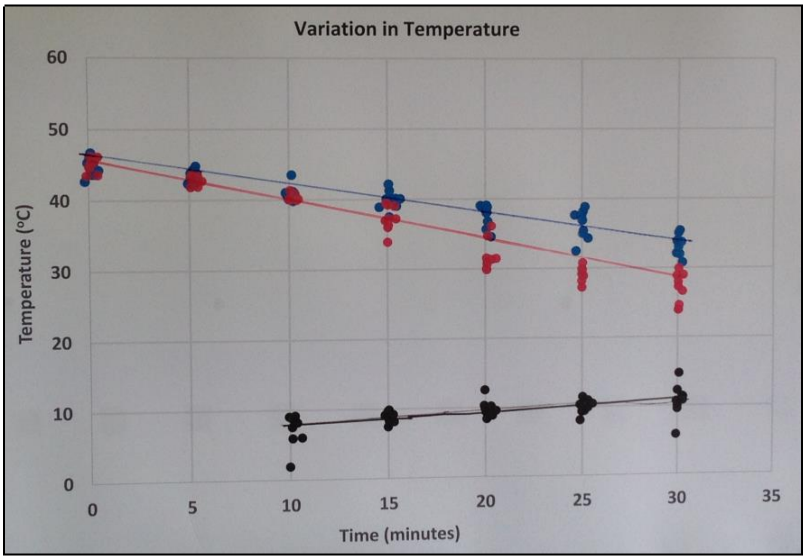

Figure 3. Class plot.

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Student Interviews

Fifty-three Year 3 students ranging in age from 8 to 9 years completed the "Heat Is On!" investigation. Following the investigation, the students who had consented to be part of the research were interviewed one-on-one by members of the research team to evidence their understanding of heat, insulation, and heat transfer. The interviews were 10 minutes in duration. For each class, the students were interviewed in alphabetical order based on their surnames. Interviewing continued until the time allocated expired; hence, not all students in the two classes were interviewed. A total of 36 students were interviewed (21 in Class A and 15 in Class B). All interviews were audio- and/or video-taped with participant consent.

Semi-structured interviews (Fontana & Frey, 2003) were conducted to capture the students' ideas about heat transfer and the effect of insulation. The aim was to provide the opportunity for the students to expand on their ideas and be asked to clarify points made. The students were given considerable freedom throughout the exchange to comment on the student investigation expereince and to make connections to other familiar contexts. The interview schedule consisted of six questions. Initially, the students were asked two questions:

1. *How does temperature vary when something gets hotter or colder?*
2. *What is the effect of the insulation on how the temperature varies?*

They were then shown a copy of the final class graph (Figure 3) before being asked the following four questions.

3. *What is the story the final graph tells us about?*
4. *Why do you think the temperatures in the clusters of data are not exactly the same?*

5. *Describe the shape of the class plots. What shapes or patterns do you see?*
6. *What do the patterns in the plots tell you about heat?*

Analysis

The 36 student interview transcripts were analysed first by one member of the research team to extract comments on heat transfer, temperature and insulation, rather than general comments related more specifically to the classroom teaching activity. For the most part, the comments analysed arose when students responded to Questions 1, 2, 4, and 6 of the interview schedule. Questions 3 and 5 served to situate the students' thinking in the context of the student investigation but generated few data about their understanding of thermal concepts. Twelve of the students' interviews were found to focus mostly on describing the investigation and did not generate sufficient data about the heat concepts to be analysed. Extracts from 24 interviews are reported in this paper.

Comments extracted from the 24 interviews during the first data analysis iteration provided rich data about the students' thinking. The sample of participants comprised 14 girls and 10 boys. The interview extracts were analysed further by two members of the research team and classified according to the four categories of alternative conceptions of thermal physics outlined by Yeo and Zadnik (2001). The examples of alternative conceptions under each category were used as sub-categories to code the students' responses. An additional category was added for comments that did not align with those described by Yeo and Zadnik.

Results

The four categories of thermal physics conceptions compiled by Yeo and Zadnik (2001) proved useful for analysing the data. The data, however, were dominated by two categories, C: Students' conceptions about heat transfer and temperature change, and D: Students' conceptions about

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thermal properties of materials. The students did not display sufficient numbers to analyse for the alternative conceptions categories A: Students' conceptions of heat and B: Students' conceptions. of temperature. This is likely because the student investigation and the questions in the interview did not focus specifically on the concepts of heat and temperature. Also, the alternative conceptions compiled by Yeo and Zadnik were sourced from studies that included responses from older students and adults. It would be unreasonable to expect Year 3 students to exhibit all of the 35 alternative conceptions listed.

Five of Yeo and Zadnik's (2001) sub-categories were evidenced in the interviews. For ease of comparison, the sub-categories are numbered in numerical order according to the list of conceptions listed by Yeo and Zadnik (p. 498). Any extracts that did not align with the sub-categories listed were allocated to a *Students' additional conceptions* category. As to whether the conceptions expressed were considered alterative or scientific conceptions are reported in the next section.

- C: Students' conceptions about heat transfer and temperature change
    - **C4:** Heat and cold flow (like liquids) (*n*=8)
    - **C5:** Temperature can be transferred (*n*=11)
    - **C6:** Objects of different temperature that are in contact with each other, or in contact with air at different temperatures, do not necessarily move toward the same temperature (*n*=8)
    - **C7:** Hot objects naturally cool down, cold objects naturally warm up (*n*=7)
- D: Students' conceptions about thermal properties of materials
    - **D9:** Materials like wool have the ability to warm things up (*n*=5)
- Students' additional conceptions (*n*=15)

Salient quotations from students for each of the categories identified are used to illustrate the range of responses expressed according to four main themes: Students' conceptions about heat transfer and temperature change, Students' conceptions about thermal properties of materials, Temperature differences attributed to the properties of materials, and Environmental effects on temperature change and thermal equilibrium. Alternative conceptions and scientific concepts are denoted by AC and SC, respectively. Most of the responses expressed naïve ideas and used age-appropriate language.

Students' Conceptions about Heat Transfer and Temperature Change

Three of Yeo and Zadnik's (2001) alternative conceptions within this category were evidenced in the student interview transcripts: (C4) Heat and cold flow like liquids, (C5) Temperature can be transferred, and (C7) Hot objects naturally cool down, cold objects naturally warm up.

Heat and cold flow

Eight students made comments related to conception C4, that heat and cold flow or move in some way. Some commented that the heat or the hot water will "come out" of the cups.

> …the hot water will come out [of the cups] into the tray (AC)… all the heat will come out into the tray (AC). [Student 1]
>
> [The] hot wants to come in … (SC). [Student 2]
>
> [The heat from the two cups is going] into the cold water (SC). [Student 3]

Others suggested the cold water will be absorbed or "come in" to the cups in some way.

> [The temperature of] the ice cold water went up because the [cups] were absorbing the ice cold water (AC). [Student 4]

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> …the cold water got added [to the tray] and then it sort of got into the cups, sort of made them go colder (AC). [Student 5]

Temperature can be transferred

The most common conception evidenced about heat transfer and temperature change was that temperature can be transferred. Comments for this sub-category were made by 11 students, Examples included:

> …the temperature of the water [in the tray increased] because the ice was probably melting to make it hotter (AC). [Student 5]

> [The temperature of] the ice water went up because it got hotter and the ice was melting (SC). [Student 6]

> I think the heat went to the cold water that made the cold water melt a bit (SC). [Student 7]

> It would have cooled down from the cold water and the temperature from the hot water would have gone into the cold water and made that a lot warmer (AC). [Student 8]

> If you have hot water and then you put ice or cold water near it the ice helps cool down the hot water with the cold water (SC). So it tries to help the cold water, tries to cool down the hot water (AC). [Student 9]

Some students used prior understanding to illustrate their conception of heat transfer, as exemplified by the following.

> If it's really hot then it will make your body heat warm you up [so you] start sweating to try and get colder. And your body heat will move on to something else to warm that up (AC). [Student 10]

> So if you put a heat pack on, like, sore muscles that would loosen your muscles and make it feel better. But that would also make, like, if it was on your arm or your wrist that would make it hotter (SC). [Student 11]

Hot objects cool down, cold objects warm up

Seven students' interview transcripts evidenced they had the conception that hot objects cool down naturally and cold objects warm up naturally. For example:

> By 15 minutes [the ice water] started to get warmer, and the ice started to melt and then the ice was very small and it was like almost water and then it was water, but it had been in the sun and so the water was getting warmer but the hot water [in the cups] has gotten colder because cold water and hot water usually make it go opposite (SC). [Student 11]

> …if you leave the cold water out [all day] it will turn hot and if you leave the hot water out it will turn cold (SC). [Student 12]

Students' Conceptions about Thermal Properties of Materials

For this category, responses were coded against one of the sub-categories: Materials like wool have the ability to warm things up.

Materials have the ability to warm things up

Five of the 24 students made reference to the notion that materials, in this case insulation, have the ability to warm things up. Some drew on their experience of the teaching activity, referring specifically to the insulating cup and its ability to warm the water:

> [The insulating cup] made it warmer (AC). [Student 3]

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Others used prior knowledge and familiar contexts to explain their thinking.

> Like in a house insulation in the roof … keeps like warm air in (SC) or like it makes it a lot warmer (AC) … it's kind of like a jumper around the house. [Student 6]

Temperature Differences Attributed to the Properties of the Materials

The responses that did not align with Yeo and Zandik's sub-categories are presented under this section. Responses given the code, Students' additional conceptions, were assigned to a new sub-category: Temperature differences are attributed to the properties of the materials. This newly established conception was evident in over half of the students' responses (n=15). Many commented that the polystyrene cup (the insulating layer) "protected" the plastic cup in some way. Other terms used to describe the protecting properties of the material included "stopped", "contained" and "shielded". All the responses under this sub-category were considered scientific conceptions because they expressed the idea that the insulation prevented the transfer of heat in some way.

> [The two cups behaved differently] because one of the cups had another cup around it which was protecting it more. (SC) [Student 13]

> The non-insulated one was getting colder quicker than the insulated cup because the insulated cup had another cup protecting it (SC). [Student 5]

> [The inner cup] got like … a protection … So the [outer] cup is like the padding we put in the attic to keep us warm in winter (SC). [Student 14]

> The non-insulated cup cooled down faster than the insulated cup because … it had something around it to keep the water warmer (SC). [Student 6]

> [The insulating cup] stopped the cold water getting near to the hot water (SC). [Student 4]

> [The non-insulated cup is] not contained so it will get cold faster. But the [insulated cup is] contained so it is still hot-ish (SC). [Student 11]

> [The] insulated cup had another cup around it so it was staying warmer because … it is like shielded. … [It] was like the cold was the army and the one who is insulated has got like a shield. And the [other] one doesn't have anything to defend themselves so it gets colder (SC). [Student 15]

Environmental Effects on Temperature Change and Thermal Equilibrium

Although not thermal concepts, the student interview transcripts evidenced students' understanding of the environmental effects on temperature and thermal equilibrium. Analysis of the 24 interviews revealed that a third of the students had a good, basic understanding of thermal equilibrium. The students commented that over time the temperature of the water in the two cups and the tray would equalise or become the same, as exemplified by the following comments.

> [If we waited 3 hours] that one would probably be … around the same amount as the [other cup]. Because it's like the water would have gotten a little bit warmer because it has been 3 hours and it has just been sitting there. [Student 15]

> [Over time] the cold one was getting warmer and the warm ones getting colder, so they were sharing the temperature. [Student 16]

> If you leave water, like if you put warm water with cold water, cold water heats up. … [They] share the heat … [Student 17]

A third of the students (n=8) also displayed a good understanding of "room temperature" and the effect the environment has on the transfer of heat.

> Because if it's cold well the hot water will turn cold like the room … and maybe the cold water gets hot in the room (SC). [Student 14]

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> This classroom is medium [temperature] and if say the sun starts shining right through that window this room would get hotter and hotter and hotter. And then if the sun went away and it started blowing a cool breeze and that door was open or that window was open, it would get colder and colder and colder. So the weather [makes the temperature vary] (SC). [Student 11]
>
> So … maybe you are moving from a cold place to a warm place back and forth. Be walking from a cold spot in the room to the warm spot in the room … and it could change the temperature of what your body heat is (SC). [Student 16]
>
> …if they for instance are near a heater and they poured cold water in [the tray], the heater might make the water hotter (SC). [Student 18]

Discussion

A feature of the student investigation reported in this paper is that the students carried out the experiment. They set up the equipment, made observations, recorded results, and represented the data. This hands-on experience allowed them to be active in the construction of their understanding and had a meaningful context from which to draw when asked questions. Much research that has explored students' understanding of heat and heat transfer utilised questions about contrived situations and scenarios either in a survey or interview. Few research studies have explored students' understanding within the learning context. It is the research team's contention that collecting data from students' during or after conducting an investigation, provides direct evidence of students' thinking and reasoning.

For the most part, the students in this study demonstrated some of the same alternative conceptions about heat transfer and the influence of thermal insulation reported previously in other studies (e.g., Kesidou & Duit, 1993; Rosebery et al., 2010). The results affirm the body of knowledge already established but also adds new insights into students' understanding. This was achieved by exploring the students' alternative conceptions in tandem with the scientific conceptions. Previous studies did not report that aspect of student understanding. The naïve ideas and language illustrated in the students' quotations provide starting points for developing learning experiences that challenge students' conceptions and support further development. As Keeley (2012) suggests, establishing the alternative conceptions as well as scientific conceptions has the potential to improve student learning and strengthen teaching practice.

Contrary to other studies (e.g., Paik et al., 2007), this study found the Year 3 students had an acceptable understanding of equilibrium. An alternative conception reported by Yeo and Zadnik (2001) states, "Objects of different temperature that are in contact with each other, or in contact with air at different temperatures, do not necessarily move toward the same temperature" (p. 498). The students in this study were able to describe the way in which the water in the cups and the tray "shared" the temperature. This suggests they have a basic understanding of equilibrium.

Also unique to this study is the way in which the students expressed conceptions of the properties of insulation. This may be attributed to the nature of the experiment undertaken by the students. Because the experiment was designed to explore the influence of insulation, it is not surprising the students focused on that aspect of the experiment. Another feature of the student investigation was the recording of temperatures in a context where the temperatures decreased. Often, previous research explored students' understanding of observations made from experiments that utilised contexts that involved the temperature rising (e.g., Erikson, 1979; Shayer & Wylam, 1981). The results from this study suggest that changing the context of exploring students' understanding of heat transfer is likely to draw out different conceptions. As Paik and colleagues (2007) suggest students' conceptions of heat and temperature are dependent on the situations within which ideas are explored.

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Conclusion

There are numerous concepts within the breadth of the science curriculum that need to be understood in terms of common alternative conceptions for teachers to be able to promote learning and support the development of scientifically acceptable conceptions. Although work regarding the alternative conceptions of heat has begun it is yet to be considered comprehensive. This is likely to be the case for many concepts within the STEM disciplines.

In 2015, the Australian Government implemented the *Restoring the Focus on STEM in Schools Initiative*, which implemented projects to promote inquiry-led teaching in mathematics, introduce computer coding across the curriculum, support educational and career pathways, and provide access to learning programs for high-achieving school students from underrepresented groups such as female, indigenous, and disadvantaged backgrounds. Although welcome, the initiative does not focus explicitly on the teaching and learning of particular concepts associated with STEM disciplines.

As well as exploring and explicating young students' conceptions of heat, this paper seeks to remind the STEM education and research stakeholders that although there is value in exploring ways in which to address the broader issues identified in the Australian Government initiative, attention still needs to be focused on student learning and understanding of particular discipline concepts and how those concepts can be promoted, challenged, and enhanced during the compulsory and post-compulsory years of schooling. To realise the Australian Government goals of promoting economic growth, instigating international collaborations, developing new ideas and products, and developing a skilled and dynamic workforce in the future (OCS, 2014), it is necessary for students to be able to understand and apply fundamental concepts relevant to specific disciplines and then experience utilising explicitly those concepts within other discipline contexts. This implies pedagogical practices are needed that align with the aims and goals of each discipline individually, yet still serve the "greater good" of the STEM collective.

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