JOURNAL OF BALTIC SCIENCE EDUCATION

ISSN 1648-3898

PRIMARY SCHOOL CHILDREN'S IDEAS OF MIXING AND OF HEAT AS EXPRESSED IN A CLASSROOM SETTING

Jesper Haglund,
Fredrik Jeppsson,
Johanna Andersson

Abstract. *This study investigates primary school children's (7-8 year-old, N = 25) ideas of mixing of marbles and of heat, expressed in small-group predict-observe-explain exercises, and drawings representing the children's own analogies in a classroom setting. The children were typically found to predict that marbles of two different colours would mix when rocked back and forth on a board. This idea of mixing is slightly more advanced than previously reported in the literature. The children's ideas of heat included reference to warm objects, their own bodies when exercising, and the process of one warm solid object heating another object in direct contact. In addition, through scaffolding, some of the children expressed a substance view of heat. Finally, the potential and challenges in probing children's ideas through a combination of data collection techniques in a classroom setting are reflected upon.*

Key words: *heat, mixing, children's ideas, primary school, classroom setting.*

Jesper Haglund
Linköping University & Uppsala University, Sweden
Fredrik Jeppsson, Johanna Andersson
Linköping University, Sweden

Introduction

Foundational studies in science education research on children's understanding of thermal phenomena have been conducted by means of interviews, with or without the use of educational equipment (e.g. Albert, 1978; Piaget & Garcia, 1977; Piaget & Inhelder, 1975). Since the 1970s, a large number of studies on students' developing understanding of thermal science have been conducted, but such studies primarily relate to ages from 10 years and above. In addition, in the last decades, the social dimension of learning has been increasingly recognised in science education research, not least with the upsurge of sociocultural perspectives. Against this background, there is a glaring void of studies of young children's ideas of thermal phenomena as expressed in social settings, which are ecologically valid with regards to the school practice. Building on previous analysis of 7-8-year-olds' analogies (Haglund, Jeppsson, & Andersson, 2012), the aim in the present study is to provide a reanalysis of the collected data with a focus on the children's ideas regarding two key concepts in the thermal domain – heat and mixing – in a classroom setting. The children's ideas were expressed in group exercises with POE (predict-observe-explain) experiments (White & Gunstone, 1992), drawings representing their own analogies for the phenomena, and their oral explanations of the drawings.

Investigating Children's Ideas in a Classroom Setting

There are several lines of research that take a direct interest in the school practice. For instance, in a *case study* the researcher investigates an environment for a longer period of time, either as a participant or a bystander, but typically in a way that does not interrupt the practice (Cohen, Manion, & Morrison, 2011). *Design studies* in the classroom, in contrast, involve explicit intervention in the teaching practice, in the form of iterative development, testing and assessment of teaching sequences, targeting domain-specific learning processes (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). The present study involved intervention in the school practice in the domain-specific area of science education, but not with a dedicated goal to study or induce learning through iterated teaching activities. The intention was rather to broaden the set of approaches to investigating children's ideas or understanding of the involved phenomena. The study thereby adheres closely to the research and teaching program initiated with White and Gunstone's (1992) *Probing understanding*, where they suggest more imaginative ways of assessing students' ideas beyond traditional written tests.

The school classroom is a very dense social environment, designed to be conducive to learning, where the children interact with their peers and teachers in carrying out tasks in constant communication. This is captured in the notions of a *zone of proximal development (ZPD)* (Vygotsky, 1978) and *scaffolding* (Wood, Bruner, & Ross, 1976), focusing on the difference between what a child may achieve by him- or herself and when assisted by somebody with more experience and an advantageous environment at large. In particular, the benefits of *peer collaboration* in learning have been motivated on the basis of the individual students' confrontation and reconciliation of the differing conceptions among the peers (Piaget, 1932), or converging, mutual construction of knowledge (e.g. Lemke, 1990).

Then again, it has been questioned within sociocultural traditions whether it is worthwhile theorising about individuals' knowledge, overall. Knowledge – it is claimed – is simply not something that an individual has or has not, but something that develops gradually in participation in social practices (Ivarsson, Schoultz, & Säljö, 2002). However, an exclusive sociocultural focus on the activities in the classroom in terms of participation comes along with the risk of ignoring the children's conceptual understanding or learning of a particular content (Sfard, 1998). The present study combines recognition and taking advantage of the social environment in class with an interest in children's ideas in relation to science content, in the midst of the full complexity of the school practice.

One of the techniques that White and Gunstone (1992) propose for probing students' understanding is *'predict-observe-explain' (POE)*. The approach can be adapted for different settings, but typically involves a teacher exposing students in class to a series of 'specific events', such as experiments. The students are first asked to *predict* what will happen in the event, and write down their predictions individually. Next, the students *observe* and report what actually happens when the experiment is performed. Finally, they are encouraged to *explain* what happened and reconcile any inconsistences, compared to their predictions. Another potential technique for investigating students' ideas and how they develop is to ask them to come up with their own *analogies* for encountered phenomena (Haglund & Jeppsson, 2012; Mason & Sorzio, 1996; Mozzer & Justi, 2012). Student-generated analogies have been found to be particularly productive in encouraging students to 'talk science' (Lemke, 1990) and take ownership for their own learning (Haglund & Jeppsson, 2012). Even young children have been found to be capable of generating analogies in relation to science content in a classroom setting (Haglund et al., 2012; May, Hammer, & Roy, 2006). It has been recognised that analogies are 'double-edged swords', in that they may be used to reinforce student ideas that are not in line with sanctioned science (Glynn, 1989), but in probing students' ideas, this may be turned to an advantage. Also when the particularities of students' analogies are different from the current science position, they nevertheless offer some insight into the students' ideas, and from where the learning process will have to start in class.

Analysis of *children's drawings* provides an additional approach to the matter. Adopting a Vygotskian framework, Brooks (2009) argues that a teacher or researcher can rarely interpret children's ideas of phenomena by merely looking at their drawings of the phenomena. It is only when researchers talk to the children about their drawings that they can get insight into the children's ideas. Similarly, Ivarsson et al. (2002) see students' drawings as resources or tools for their process of reasoning, rather than straightforward mirrors of their ideas, in their socio-cultural account of student's understanding of the Earth, gravity, etc. From this perspective, the drawings may also serve as a *shared object of attention*, a point of departure for dialogue (Schoultz, Säljö, & Wyndhamn, 2001).

Young Children's Ideas of Heat and of Mixing in Science Education Research

As argued above, a large number of studies have been performed in educational psychology and science education research regarding students' ideas of *heat*, but only a minority of them have included children as young as 7-8 years of age, and most of those, in turn, have been performed in a Piagetian psychology laboratory setting. Overall,

ISSN 1648–3898

Piaget and Garcia (1977) argue that children's understanding of heat and light is delayed by one developmental stage compared to their understanding of mechanical phenomena, due to the abstract character of the phenomena and that children cannot coordinate physical manipulation with seeing the effects of their actions. In particular, in heat conduction experiments, Piaget and Garcia found that children in stage I, typically up to the age of six years, did not conceptualise heat as something that passes from a warm object to a cold object through conduction, but rather in terms of 'contagious action', influence by proximity. In conclusion, such knowledge develops as children approach 11 years of age: "Only in stage III is conduction understood" (Piaget & Garcia, 1977, p. 112).

Albert (1978) studied conceptions of heat among children of age 4-9 years by use of individual interviews with probes such as "Give me examples of heat" or "What is the hottest thing in the world?" without a physical, experimental set-up. Based on these interviews, she categorise conceptions in age-dependent stages in the tradition of Piaget. Albert found that before the age of six years, children have developed the idea that objects can be hot and that such hot objects make them warm. She also found that by age seven or eight years, children become aware that hot objects are hot only under certain conditions, such as when switching on a plate, and that hotness is not an inherent characteristic of the object. By this age, in parallel, the children also start to see heat in terms of a process, for example that something may be warmed up by the sun, and begin to associate heat to their body getting warm when they exercise. After this stage, around the age of eight years, children start to differentiate between heat and an object in which the heat resides, a view of heat as spatially located, extended, and moving from one object to another, characterised by Albert as a view of heat as a substance.

The question of at what age children typically embrace a substance view of heat, and its potential usefulness in teaching, has remained a particular focus in science education research, with inconsistent results. In their literature review of conceptions of heat and temperature, Erickson and Tiberghien (1985) claim that the substance notion of heat is used extensively by children to account for heat transfer by means of conduction, from personal experience of having touched warm objects, such as stoves and light bulbs. They give the example of an interview with a 12-year-old who conceptualises the heating of a metal rod by holding one of its ends under a flame in terms of heat that moves from this end throughout the entire rod. Howe (1998) interviewed children of ages 6-15 years regarding their conceptions of different physical phenomena, including heat transfer. Assisted by photographs of the scene, she asked the children to argue for which pan of a selection of four is best for heating water on a cooker, and which fork out of four would keep a cook from being burnt when cooking. In contrast to Erickson and Tiberghien, Howe concludes that before the age of 12 years, very few of the children described the mechanism of heat transfer through the pan as 'transmission', i.e. a flow of heat through the pan, but in other ways, closer to Piaget and Garcia's (1977) description of 'contagious action'. Lautrey and Mazens (2004) studied the conception of sound and heat among French 8-year-olds. By means of interaction with the phenomena through experimental set-ups together with the children in individual interviews, they investigated whether the children attributed sound and heat in a stable way to properties of objects (substantiality, having weight and permanence) or properties of processes (e.g. transmission by adjacency), following the approach of ontological categorisation (Chi, 2005). Their conclusion is that the children at this age gradually abandon a conception of heat as an object and develop the view of heat as a process, largely reversing the development found by Albert (1978) among children in the age group.

Paik, Cho and Go (2007) have studied conceptions of heat and temperature among Korean 4-11-year-olds. Interestingly, 4-year-olds had more correct responses to some of the items than the older children, which may be due to their common sense answers and misconceptions formed in school among the older students. For instance, when asked about the temperature of the result when mixing water at 40° C with water at 70° C, the 4-year-olds had more correct answers than the 5-8-year-olds. This may be due to the 5-8-year-olds having formed the misconception of temperature as an additive quantity, but alternatively that they have adopted the approach from mathematics teaching that when given two numbers, they add them without considering the phenomenon, supporting similar findings reported by Erickson and Tiberghien (1985).

Children's interaction with heat-related phenomena has also been studied in collaborative settings, although typically not involving children as young as in the present study. Howe et al. (1995) let children of age 8-12 years collaborate in groups of four in investigating experimentally the cooling of hot water in containers, varying in different respects, such as material and thickness. From pretests to posttests, the children referred significantly more to the thickness and surface area of the containers. In addition, the condition of using critical tests, i.e. comparing pairs of containers that differed only in one variable, in combination with rule generation, i.e. writing down factors that are relevant to how quickly hot water cools down, were found to give better explanations of the processes of heating and cooling. Rosebery, Ogonowski, DiSchino and Warren (2010) present a design experiment with a combined class of third- and fourth-graders, regarding thermal phenomena. After a series of activities, including experiments with melting ice cubes, a pivotal event occurred when the children evacuated the classroom due to a winter fire drill, without their coats. When they came back, a dialogue started where the children related this experience of freezing to the taught subject in terms of a temperature difference and that normally "the coat traps all your body heat" (p. 334), but now it went out from the body to the cold air. In other words, the children came to conceptualise 'heat' as an independent object or substance as part of the teaching effort.

In turn, the phenomenon of *mixing* relates both to the area of thermal science and the notion of chance, since the second law of thermodynamics deals with the directedness of natural processes, and objects are typically more likely or tend to spontaneously mix, rather than to remain separated or 'unmix'. In their investigation of children's conceptions of mixing, Piaget and Inhelder (1975) conducted individual interviews by interacting with a seesaw-suspended board containing marbles of two different colours that were initially separated but then mixed as the board was rocked back and forth, and asking the children to predict and make drawings of what would happen. In the preoperational stage I (typically children up to age 7), the children predicted that marbles of different colours would not mix, but simply swap places or follow another structured pattern. In stage IIA (early concrete operational stage; children about 7 to 9 years old), the children acknowledged that the marbles might become mixed as an unstable unnatural state, but argued that the marbles would eventually end up in the natural, original separated state. In stage IIB (late concrete operational stage; about 8 to 11 years old), the children realised that the marbles would collide and become increasingly mixed, but had difficulties coordinating trajectories of individual marbles and their final positions in drawings. Finally, by stage III (formal operational stage; 11 to 12 years old), the children could coordinate trajectories with final positions and, most importantly, had grasped the law of large numbers: that it is possible, although very unlikely, that the marbles would return to their original separated state. With a similar approach, Shultz and Coddington (1981) found that approximately 40% of six-year-olds predicted that coloured marbles would mix in a randomized manner, compared to about 75% among 9-year-olds.

Friedman (2001) studied children's grasp of spontaneous processes to follow their development of an intuitive understanding of entropy. By using pictures of an initial state and an end state of an event, children were found to be sensitive to an asymmetry of natural causes from the age of four years. Events that involved change from an ordered state to a disordered state were regarded by the children as possible by natural causes significantly more often than events in the other direction. Events from disordered to ordered states – such as mixed-up paper cups or beads becoming ordered – were seen as having to be caused by means of human agency or by 'magic'. Similarly, in eye tracking experiments with infants looking at computer animated movies, Newman, Keil, Kuhlmeier and Wynn (2010) found that 12-month-olds were sensitive to the difference between a rolling ball creating order among a disordered set of blocks, compared to the reversed disordering event. However, the effect disappeared when spots were added to the ball to form a face and the ball moved towards the blocks with the eyes facing the direction of motion, indicating sensitivity to the difference between conscious agents and inanimate objects in inducing order.

Purpose of the Research

The present study relies both on cognitive and social traditions of educational psychology and science education research. On one hand, the overall goal was to understand the ideas or views of science content related to heat and to mixing among the participating children, assuming a cognitive perspective (e.g. Piaget & Garcia, 1977; Piaget & Inhelder, 1975). In particular, two objectives were to investigate how POE and the children's representations of their own analogies in drawings, respectively, might be used as approaches to probe their understanding of the involved phenomena and concepts. On the other hand, the research design and data collection approaches have evolved in social traditions, taking advantage of richer social practices (e.g. Rosebery et al., 2010) than what is typically achieved through, for example, individual clinical interviews. Although still in a research setting, a set-up was adopted that is similar to regular classroom practices, trying to come close to an authentic school setting in the sense of what might happen in school. Due to the explicit focus on children's ideas of heat and of mixing, the data have been analysed in relation to existing categorisations of children's ideas reported in the literature typically in terms of Piagetian conceptions. In particular, attention has focused on how these ideas are expressed in different contexts.

Accordingly, the research was guided by the following research question: *What ideas of mixing and of heat do first-grade children express as they interact with physical experiments and generate their own analogies for related phenomena through drawings in a classroom setting?*

ISSN 1648–3898

Methodology of Research

General Background of Research

The present research was conducted as an intervention in a primary science classroom. The participating children were introduced to the idea of analogies, interacted with two physical experiments relating to the concepts of heat and mixing, respectively, and asked to come up with their own analogies for the phenomena and represent them in drawings.

Sample Selection

The participants in the present study were one class (N = 25) of Swedish first-grade pupils (aged 7-8 years). The children were used to collaborate with each other and to partake in group discussions and had experience of thematic science teaching, but had not encountered thermal phenomena or been explicitly introduced to analogies in previous teaching. Informed consent was received from the parents of all participants. The analysis focuses on the dialogue between five of the children, due to their dynamic interaction and expression of a broad range of ideas with regards to the experienced phenomena. The small sample of participants in focus is motivated primarily by the qualitative approach to describing what ideas the children express in different contexts.

Instrument and Procedures

First, the children were introduced to the notion of 'analogy' in a full-class lecture setting, by comparing pictures of a car, a bicycle, and a walking girl, representing a more distant category. The children contributed to pointing out in what respects the pictures are similar, such as all of them being related to propagation forward, and where they differ.

Second, the children were divided into smaller groups where they experimented with either mixing of marbles or heat transfer together with one of the researchers. In this phase, the POE approach was used, where the children in the small groups were asked to tell the researcher their predictions and explanations of the phenomena and compare their answers (White & Gunstone, 1992). The POE approach was altered in that we did not ask the children to write down their predictions or explanations, due to their young age.

The mixing of marbles was introduced to the children by one of the researchers (JH) through use of a flipping board, suspended like a seesaw, containing seven dark and seven light marbles, which were separated by a plastic devise. The approach followed that of Piaget and Inhelder (1975), but in a group setting and without giving the children fixed alternatives of what may occur to choose from. The children were asked to predict what would happen if the board was flipped back and forth once, and observe and explain the outcome of the experiment. The exercise was repeated with two and ten flips and an imagined one thousand flips. In the heat transfer POE exercise, in turn, FJ asked the children to interact with a hot-plate and a frying pan in different conditions: the plate switched off, the knob switched to 1 and to maximum. They were asked to touch the metal part of the frying pan (or feel the 'heat' of the air close to it when warmed up by the plate) and its plastic handle. They also observed how water rapidly boiled off when it was poured into the hot pan.

Third, the children were placed around tables in groups of 5-6, and asked to make their own analogies to the experienced phenomena, expressed in terms of 'other things that work in the same way'. The children were encouraged to represent their analogies in the form of drawings and explain the connections between their drawings and the phenomena.

In a follow-up data collection exercise, two weeks after the first data collection, the groups were swapped, so that the ones that had dealt with the heat transfer exercise now experienced the mixing of marbles and vice versa. The data collection approach was altered slightly, as the children were asked to make drawings of the marble trajectories in templates of the flipping board following Piaget and Inhelder (1975), and the flowing heat in templates of the stove and the frying pan.

All sessions of the study were video and audio recorded, and some of the episodes were selected for transcription and further analysis, and eventually, translation into English. A full *verbatim* transcription was not feasible, due to low audio quality in some of the analogy-generation episodes. In addition, the children's drawings were collected.

Data Analysis

The children's ability to interpret and generate analogies has been reported previously (Haglund et al., 2012). In the present study, the analysis focused on probing the children's ideas of the experienced phenomena. The ideas expressed by the children were matched with categories that have been described in previous research. In particular, the following ideas of mixing were used, following Piaget and Inhelder's (1975) descriptions of children's reasoning at different developmental stages:

- *Structured pattern.* Marbles will not mix, but arrange in a structured pattern (Stage I).
- *Mixing and return to original position.* Marbles will mix, but tend to return to their original, natural positions (Stage IIA).
- *Emerging probabilistic view of mixing.* Recognition of collisions and mixing of marbles, but difficulty in coordinating trajectories and end positions (Stage IIB).
- *Probabilistic view of mixing.* In addition to conditions of stage IIB, coordination of trajectories and end positions and grasp of low probability of marbles to return to the original configuration (Stage III).
-
- The following classification scheme was used for ideas of heat:
- *Hot bodies.* There are hot objects, which may warm us. This idea has developed before the age of 6 years (Albert, 1978).
- *Conditional nature of hot objects.* Hot objects are hot under certain conditions (such as when a plate is switched on), an idea that develops by 7-8 years (Albert, 1978).
- *Process view of heat.* Thermal phenomena are conceptualised as a process of an object getting warmer or heating another object. For instance, objects may get warmed up by the sun or children get warm when they exercise. Such ideas also develop by the age of 7-8 years (Albert, 1978). A particular way of characterising heating processes is in terms of contagious action across adjacent bodies (Piaget & Garcia, 1977).
- *Heat as dependent on the material.* Different materials insulate or conduct heat (Howe, 1998).
- *Substance view of heat.* Heat is a substance in warm objects that may flow to colder objects. There are different findings as to at what age a substance view is adopted (Albert, 1978; Erickson & Tiberghien, 1985; Lautrey & Mazens, 2004).
- *Heat as an independent entity.* Heat is seen as differentiated from objects in which it resides, and localised and extended in space. This ideas develops by the age of 8 years, and is, according to Albert (1978), part of the substance view of heat.

Results of Research

Ideas of Mixing of Marbles Expressed in a POE Group Exercise

Stefan, Hanna and Maria participated together with five other children sitting around a table, as one of the researchers (JH) guided them through the POE exercise with the marble board. In the exercise of generating analogies for the phenomenon and representing them in drawings, the children were separated into two groups, where Maria and Stefan sat next to each other in one group. The following dialogue takes place initially when the eight gathered children are asked to guess or hypothesise what will happen if the board is flipped back and forth once:

> JH: What do you think happens to the marbles?
> Stefan: All these ones will go there and those will go there [gestures that all dark and light marbles will swap places] /…/
> Maria: I think that it will mix… different colours in different places… /…/
> JH: So what do you think it will look like on this side? [Points to one side of the divider]
> Maria: That there will be some dark ones and some light ones and the same on the other side. /…/
> Hanna: It will mix. /.../ Some of the dark ones will be on the side where there are light ones, and some light ones are among the dark ones.

ISSN 1648–3898

In this excerpt, Stefan first expresses his hypothesis that all marbles will swap places across the divider, thereby adhering to the *structured pattern* way of reasoning. Maria, on the other hand, expresses that she thinks that the marbles will mix. JH asks all children in the group in turn to guess what would happen, and the remainder of them support Maria's hypothesis that the marbles will mix, typically phrased in terms of some of the light ones changing sides and the same for the dark ones. At this initial stage, there is not sufficient data to reveal whether they adopt a probabilistic view of the phenomenon, or if they think that the marbles eventually will tend to return to their original positions. What can be noted, however, is that in this social setting, the children can hear each other's ideas of what will happen, and are thereby given the chance to reflect upon their own ideas.

After asking the children to make predictions, JH flips the board back and forth, and asks the children to describe what they observe. The experimental result is that the marbles mixed in all POE sessions, albeit with some variation in how many marbles of each kind end up on each side. Next, JH asks what will happen if the board is flipped back and forth again, and the children respond:

> Stefan: It gets mixed. They will go so and then they will go so [shows the path of the marbles with his finger as they bounce on the other side of the board and cross the divider].
> Alfred: I think that it mixes.
> Hanna: I think so, too [looks at Maria].
> Maria: Yes.
> JH: So what will be the result? What will be on this side [points to one side of the divider] and what will be on this side [points to the other side of the divider]?
> Stefan: There will be more on this side [points to one side of the divider]

After some of the marbles switched sides in the first flipping, there is now a consensus that the marbles will mix when the board is flipped again. Now also Stefan adopts the view that the marbles will mix, given the experience of the first round and the social scaffolding provided by his peers. It may be worth noting that none of the children expresses that the situation of the marbles getting mixed is unnatural in any way, so there is no indication of them adopting the idea of *mixing and return to original position*. Instead, in this situation, all adhere to a *probabilistic view of mixing*, arguably of the *emergent* kind, since they do not express that the marbles might return to the original position, although unlikely. Apart from the mixing pattern, the children also focus on where there would be more marbles, on which side of the divider, regardless of the colour, as exemplified by Stefan's last utterance.

The children largely keep the idea of the marbles getting mixed also when predicting what happens as the board is rocked back and forth ten or an imagined one thousand times:

> JH: If I would flip the board back and forth one thousand times, what do you think would happen then? We will not do that, but just guess.
> Stefan: We will not have time, 'cause we will die…
> JH: No, I think it would take about five minutes… so it would be boring, but we would be able to make it…
> Alfred: It would mix…
> Stefan: No it won't…
> JH: It won't mix?
> Stefan: No.
> JH: What's the opposite of mixing then, would you say?
> Stefan: Well, how would I know? I'm just guessing. [the children laugh] /…/
> JH: …if we flip one thousand times, could it be that they separate, so that all white ones will be on this side [points to one side of the divider] and all dark ones on that side [pointing to the other side]?
> Stefan: No. /…/
> Maria: No, I think it will be very mixed.
> Hanna: I think so, too.
> JH: What do the rest of you think?
> Children: Mixed!

This excerpt, however, also shows one of the challenges in inferring about children's ideas from things they say. Here, Stefan has possibly started to grow tired of the exercise, and in imagining a one-thousand-flip, he says: "we will die". This is likely an exaggerated expression for that he would get bored, rather than his genuine belief of what would happen. Next, Stefan hypothesises that the marbles will not mix. Even though we think that also this assertion reflects his boredom, more than his underlying ideas of mixing, it is used productively in the dialogue as a position against which the other children may provide opposing views. Eventually, the consensus position is that the marbles would be mixed if the board was rocked back and forth one thousand times, and the children take a stance against the alternative of the marbles separating. There is still no evidence of a genuinely probabilistic line of reasoning, so the group expresses an *emerging probabilistic view of mixing*. Even now when the marbles were as mixed up as possible, the children still predicted that the marbles would mix. This may be an indication that they had generalised the idea of increasing mixing but took the idea too far in this case. An alternative interpretation is that they identified mixing with the process of rocking the marbles back and forth, rather than focusing on the resulting final configuration of the marbles.

Ideas of Heat Expressed in a POE Group Exercise and in Analogy Drawings

At the second day of data collection, FJ worked with the same group on the heat exercises. Stefan did not take part in the exercise, but Karolina and Annika, who had been absent the first day, joined the group. In all, they were five children. FJ starts by asking what happens if he turns the knob of the plate to one, and Karolina raises her hand and says: "It gets a bit warm". At this initial stage, she expresses a *process view of heat*, with a focus on the plate getting warm. In addition, her realisation that the plate is not always warm, but that it depends on our actions reveals an understanding of the *conditional nature of hot objects.*

After the plate has started to warm up, FJ places a frying pan on the plate and asks where the heat in the plate goes. Hanna answers: "It goes there", and points to the part of the frying pan in contact with the plate. Next, FJ asks the children to touch the part of the pan in contact with the plate briefly and the children comment that it feels tepid and nice. However, when he asks them to touch the handle, they find it to be cold:

> FJ: Why is the handle cold, then?
> Tomas: 'Cause this [points to the cold plate beneath the handle] is not warm.
> FJ: 'Cause this one [touches the cold plate] is cold?
> Tomas: Yes.
> FJ: What if I turn it this way [turns the handle so that it sticks out outside the stove]?
> Karolina: Then it is 'cause it doesn't get up here [gestures movement from the metal part of the pan to the handle]
> FJ: Doesn't the heat get here [points to the handle]?
> Karolina: No. Otherwise, you'd burn yourself.

At the beginning of this episode, FJ introduces a *substance view of heat* when he asks where the heat in the plate will go. Hanna's adequate reply "it goes there" in reference to the heat shows that she adopts this view. Similarly, Karolina uses a substance view when she explains why the handle is not warm. Since the studied phenomenon involves heat conduction through solid matter, these instances of the substance view of heat encompass the idea of *heat as an independent entity,* as something that flows in metal. Tomas, however, expresses a view that is reminiscent of heat as *contagious action*, that the handle is cold due to its proximity to a cold plate. In addition, throughout the episode and sometimes encouraged by FJ, the children use their sense of touch in determining whether objects feel cold or warm, corresponding to the *hot bodies* idea of heat. Finally, Karolina expresses a *process view of heat* in arguing logically that since you do not burn yourself when you touch the handle, you can tell that the heat has not got there.

After the plate has been warmed up for some time, Karolina explains why the handle is cold but not the rest of the frying pan by referring to a difference in materials: I know! 'Cause it isn't the same. This [points to the metal part of the pan] is maybe metal, I don't know… /…/ And this [points to the handle] maybe is some other thing… "Here, Karolina expresses a view of *heat as dependent on the material* in a productive way.

Next, FJ leaves the plate on for some time, and suddenly shuts it off:

> FJ: Now that we have so much heat in the plate, we shut off the stove. Where does the heat go then?
> Maria: [Raises her hand and gets the word] It goes back.

ISSN 1648–3898

FJ: Does it go back? [Sounds sceptical. Gestures movement down to the plate]
Tomas: No, it disappears. /…/
FJ: OK. Where does it disappear?
Karolina: Out [gestures outwards movement]
FJ: Out? [outwards gesture]
Karolina: Yes, out here… [gestures outwards] so it becomes air, maybe... No! Into the radiator, maybe… [points to a radiator under a window]

In this dialogue, FJ again applies a *substance view of heat* in asking where the heat goes. The children catch onto FJ's way of talking in imagining where the heat goes. Intriguingly, Maria and Karolina think that the heat will go to objects they associate with hotness, the plate and the radiator, in a way that goes against the second law of thermodynamics, according to which heat flows spontaneously from objects of higher temperature to objects of lower temperature. Tomas, in contrast, expresses that heat will "disappear", to which Karolina adds that it will go out into the room and become air. Karolina's suggestion that the heat becomes air reveals that she does not consistently embrace the idea of *heat as an independent entity,* but here identifies heat with the warm air itself. Similarly, across the groups, when FJ asked where the heat would go when the plate was shut off, the children said that "the smoke goes up" into the air "so that we cannot see it", that "it just floats around, like the air", and "it becomes air". Here, the heat is not contained in the smoke or the warm air; heat *is* the warm gaseous substance.

Next, the children were asked to draw and make comparisons to 'other things that work in the same way', our way of introducing analogies. Overall, it was difficult for the children to come up with comparisons, possibly due to the invisible character of thermal phenomena, and many of the drawings simply involved representing cold and warm objects, reflecting the *hot bodies* category of ideas of heat. The children also brought up that you get warm when you exercise, and drew images of themselves, adhering to the *process view of heat*.

Hanna and Karolina jointly develop an analogy between the stove and a balloon, which expresses the *substance view of heat*. The development of the analogy is initiated by Hanna:

Hanna: Could I draw a balloon…?
FJ: You can draw whatever you want, Hanna.
Hanna: Yes, I can draw a balloon. 'Cause if you blow in warm air into the balloon…
FJ: Yes.
Hanna: …then the balloon explodes… and it [the air] gets out again.
FJ: Quite right! [after not having engaged with the exercise for a while, Karolina shines up and starts to draw again, and Hanna laughs] Very good, Hanna!

Hanna and Karolina sit next to each other and discuss how to make their drawings of balloons. Karolina comments: "I will make one balloon. And then I will make another balloon that explodes." She ends up making a time series of a balloon (Figure 1, left):

Karolina: Someone blows up a balloon with her warm air [breath]… /…/ warm air into the balloon. /…/ And then she pricks the balloon with a needle. /…/ So, the balloon… what's it called… explodes… then the warm air gets out [gestures dispersion].
FJ: What would you say that this is the same as?
Karolina: As… what's it called… when you turn off that [the stove], then the warm [stuff] will come [gestures dispersion].
FJ: /…/ Very good Karolina! Super smart!
Hanna: I do almost the same thing. But I was the one who came up with the idea. /…/ Good that I got that idea!
FJ: Very good. It's never wrong to cooperate.
Hanna: No, 'cause I helped her.

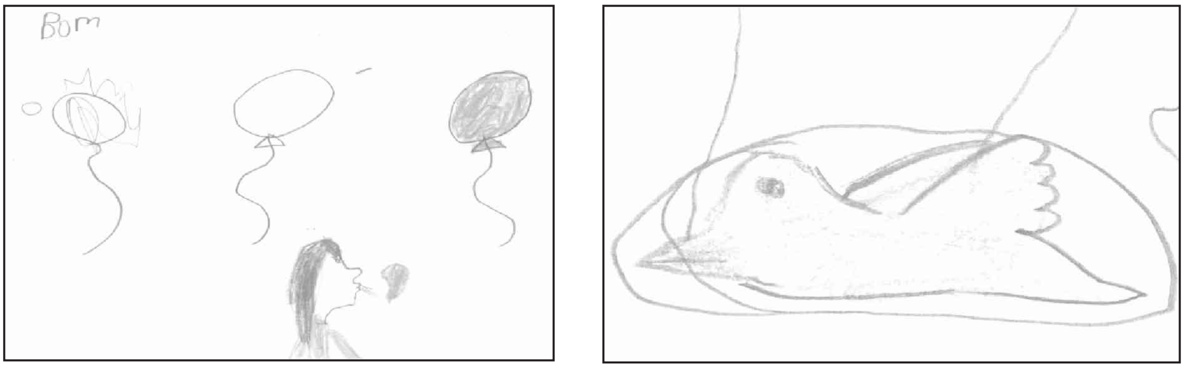

Figure 1: Karolina's time series of an exploding balloon, to be read from right to left (left); Maria's drawing of a bird, with lines connecting its parts to parts of the frying pan (right).

Here, Hanna and Karolina focus on warm air that disperses from a central object, the stove and the balloon, respectively. It may be seen as two different cases of heat transfer by convection, through the dispersion of warm gas. However, they still do not disambiguate between the heat and the warm gas and do not make use of the view of *heat as an independent entity*. Another thing to note is the social dynamics in this situation. Hanna gets the idea to compare the heat experiment to a balloon, and Karolina elaborates on it by her time series representation and making the analogy explicit. Eventually, when FJ praises Karolina, Hanna is somewhat jealous. In all, they probably come further jointly in accounting for the analogy and revealing their underlying thoughts of heat, than they would have done individually.

After the exercise, FJ asks the children to explain their drawings in turn. Maria shows her drawing of a bird (Figure 1, right) and tells:

> Maria: I have made a little bird.
> FJ: OK, that's a very nice bird, Maria. Can you tell what about the bird that is similar to the stove and the frying pan?
> Maria: Yes, under all fur [points to the drawing] it's really warm… [touches her own body] just like the frying pan… /…/ And the beak… it's like that [points to the kitchen area and makes grabbing gesture].
> FJ: Like the handle?
> Maria: Uhum [nods]

Now, FJ asks Maria to draw lines connecting what on the stove corresponds to what on the bird, and she connects the hot plate to the bird's body and the handle to the beak.

> FJ: So, is it inside the fur that is like the stove?
> Maria: Yes, because the fur gets warm… [touches her own body]
> FJ: Yes…
> Maria: And that keeps the heat inside here [points to her own body]
> FJ: OK.
> Maria: …so that it doesn't feel cold.

Maria's analogy focuses on heat being kept in one part of an object (the hot plate and the bird's body, respectively), so that it does not come to another part (the pan handle and the bird's beak). Here, she uses an idea of *heat as an independent entity*, residing in solid objects. In addition, the fact that she relates the bird's "fur" – her expression for the feathers, which keep the heat inside the body – to the frying pan, reveals awareness that some objects may confine heat so that it does not leave, pointing to an emerging idea of insulating materials, i.e. *heat as dependent on the material*.

ISSN 1648–3898

Discussion

Results Discussion

Against the background of the findings of the study in relation to previous literature, we now revisit the research question: *What ideas of mixing and of heat do first-grade children express as they interact with physical experiments and generate their own analogies for related phenomena through drawings in a classroom setting?*

As for the mixing of marbles, the children in the present study expressed many of the ideas in the analysing framework, described by Piaget and Inhelder (1975), throughout their dialogue. For instance, Stefan predicted that the marbles would form a *structured pattern*. However, overall, their ideas in this study were slightly more advanced than those of children in the same age group in the study by Piaget and Inhelder and more in line with the 9-year-olds reported by Shultz and Coddington (1981). The dominating prediction among the children was that the marbles would mix and not spontaneously separate by colour again, even if you rock the board back and forth 1000 times, reflecting an *emerging probabilistic view of mixing*. This idea was reinforced throughout the experiment that involved observing the board with marbles being rocked back and forth. Piaget and Inhelder (1975) found that this stable idea of an increased mixing was established in Piaget's stage IIB, which typically starts at the age of 8.

Apart from the children in focus in the Results of Research section, other children in the class came even further in their lines of reasoning regarding the mixing of marbles. For instance, in relation to the thought experiment of what would be the situation after 1000 flips, Lisa expressed that "if you have luck" and you "do it a bit carefully" the marbles "can get into order". Similarly, Krister said that it "could happen" that the marbles would end up separated after 1000 flips, but that the "risk" is small. In addition, as reported previously (Haglund et al., 2012), Lisa also came up with the analogy between the mixed marbles and what happens when you drop groceries on the ground and "it gets like really messy". We see these as instances of a *probabilistic view of mixing*, otherwise characteristic of children in Piaget's Stage III, typically reached by the age of 11-12 years.

When it comes to the children's ideas of heat, the findings in this study are similar to those reported by Albert (1978) and Piaget and Garcia (1977). Generally, it was difficult for the children to talk about and draw the phenomenon of heat transfer, which supports the view of Piaget and Garcia (1977) that conceptualisation of heat, which is not directly visible and accessible to direct manipulation, is delayed from a developmental perspective, in comparison to, for instance, mechanical phenomena.

The children in the present study often focused on objects being warm or cold, in adopting the *hot bodies* idea, which is typically available already before the age of 6 years (Albert, 1978). In line with children of the same age studied by Albert, the children in the present study also recognised the contingent character of heat in that objects are not inherently hot, but may be dependent on some kind of action, such as the plate being hot only if you have switched it on, reflecting the *conditional nature of hot objects*. In addition, they adopted a *process view of heat*, in referring to objects getting warmer or objects heating other objects. As we have seen, as part of the process view, the children expressed their ideas of heat conduction between solid objects as 'contagious action' (Piaget & Garcia, 1977). Furthermore, in response to why the metal part of the frying pan was warm, but not the handle, Karolina made productive use of a view of *heat as dependent on the material.* These ideas were expressed concurrently in the dialogue, sometimes by the same child.

Against the background of FJ's scaffolding, the children also expressed different kinds of a *substance view of heat*. At times, heat was not seen as independent from the hot bodies or matter in which it resides, as expressed by Karolina in saying that the heat *becomes* air as the water boils off the frying pan, but there are also examples of the view of *heat as an independent entity.* For instance, Karolina spontaneously talked about the heat not going to the handle and Maria drew a bird that keeps the heat with its "fur". However, seeing heat as an independent entity on occasion also led to odd conclusions, such as Maria and Karolina suggesting that heat might go back to the plate or to a radiator, i.e. different hot objects. In all, in line with Albert (1978), our interpretation is that at least some of the children were on the verge of appropriating a substance view of heat, as it was within their ZPD (Vygotsky, 1978).

The results of the present research with regard to the idea of heat as a substance are different from those of Lautrey and Mazens (2004), who found that the majority of children in the same age group attributed heat to an object ontology, but were in the process of abandoning it for an arguably more adequate process view. However, we suggest that Lautrey and Mazens' data may be given an alternative, complementary interpretation. First, a process view of heat is readily available among the children in our study, resonating with the findings of Albert (1978), but expression of objects getting warmer or heating other objects reflect the idea of heat as a *direct process* in Chi's (2005) ontological categorisation. Further, Lautrey and Mazens (2004, p. 410) provide the following quote as an example of a child having a substance view on heat, in response to whether heat can pass through different solid materials: "Yes because cardboard is softer. The smoke can go outside here because the box is soft and everything can go out". Here, the interviewed child expresses a view of heat as *identical* to the smoke, i.e. not independent from the object in which it resides. Such warm substances cannot penetrate a wall, by means of convection, unless it has holes in it, like a porous, "soft" cardboard wall. However, the child may not yet have adopted the idea of heat as an independent entity, which is required for grasping heat conduction through solid matter. In addition, as acknowledged by Lautrey and Mazens (2004), an understanding of heat as energy transfer, a kind of *emergent process* in Chi's (2005) terminology, lies several years ahead.

Method Discussion

There are many attractive dimensions to conducting conception research in the classroom environment. For instance, there is a value of children hearing each other's ideas of the encountered phenomena. Nonetheless, this approach to probing children's ideas also brings along challenges. In particular, in the complexity of the social setting, it is admittedly difficult to pinpoint ideas to individual children. In this study, the initiative to draw a particular motif often happened in the midst of the classroom chaos, and it was not possible to isolate the contributions from individual children in the process. Still, by means of triangulation across the different situations and approaches to data collection, it is possible to discern some patterns in the ways the individual children reasoned about these phenomena. For example, the way that Karolina came back to the view of heat as an independent entity in different situations stood out in comparison to her peers.

Regarding the influence of the social setting, there is ample evidence of the children being influenced by the researchers and their peers, i.e. making use of their ZPD (Vygotsky, 1978). For instance, we saw how Karolina and Hanna interacted in developing the analogy between the pan on the stove and a balloon. Similarly, in the marble experiment, the children were given the opportunity to hear each other's predictions and explanations of the phenomena. The richer social environment in relation to the marble experiment is the main alteration in our study to Piaget and Inhelder's (1975) design, and it is thereby a main contender for explaining the slightly more advanced lines of reasoning among the children in our study. In contrast, the children expressed a broad range of ideas in their dialogues in relation to heat, covering most of the categories developed primarily by Albert (1978), but came to apply a substance view of heat only under the influence of considerable scaffolding provided by FJ. Why is that? First, as pointed out by Piaget and Garcia (1977), it is challenging for children to conceptualise heat, since it is invisible and difficult to manipulate. In a Piagetian interpretation, it may well be that the children are not yet developmentally prepared to enter the next stage in their reasoning. However, from a Vygotskian point of view, we still had hoped that the interaction with the artefacts, the exercises and the other children would have had a larger effect on their expression of ideas. An alternative interpretation is that the children had more prior experiences of stoves than of the marble game, so that the interaction with the stove in this particular exercise did not add much to their understanding. In addition, the interaction with the stove involved more complexity than the marble board, including more senses and interaction of several objects of different material and shape, which might have required more discussion for the children to fully understand the situation.

Further, during the second day of data collection, the children found it challenging to draw the phenomena of heat and the predicted or observed paths of the marbles in templates of the stove and the marble board. Some of the drawings of the paths of the marbles reflect a structured pattern or look like a chaotic 'spaghetti Bolognese'. Piaget and Inhelder (1975) interpret the situation that children make drawings of the paths that seemingly reflect a less advanced understanding than what they say as an indication of inconsistent ideas. In contrast, we would side with Brooks (2009) in that it is difficult to infer children's underlying ideas from drawings alone; for an in-depth analysis we have to talk to the children about what the drawings are meant to represent. It is difficult to draw the event of marbles being flipped back and forth, with their trajectories depending on collisions with the walls and each other; but this is a matter of representational skills, rather than a straightforward reflection of underlying ideas. The drawings and the experiences of the experimental equipment serve as *shared objects of attention* when probing the children's ideas (Schoultz et al., 2001).

Conclusions and Implications

Primary school children's ideas of mixing of marbles and of heat, respectively, were studied in a social classroom setting, through interaction with physical experiments, and creation of self-generated analogies and drawings of the phenomena. In this social setting, the children were found to express more advanced ideas of mixing than reported in previous research relying on individual interviews with children of the same age, revealing a developing understanding of probability. In turn, in dialogue the children expressed a broad range of ideas of heat, previously typically ascribed to children in the same age group and younger. However, the children had challenges adopting the idea of heat as an independent entity that resides in warm objects.

For future science education research, it remains to establish what kinds of phenomena, learning contexts, and types and degrees of scaffolding are conducive for primary children to grasp the idea of heat as an independent entity. In particular, how would children at this young age respond to deliberate introduction of a heat-flow model, previously used in the teaching of older children? In addition, further investigation is required to assess whether the approach to probe primary children's understanding by means of a combination of POE experiments and self-generated analogies may be extended to other subjects or phenomena, beyond heat and mixing. For instance, how would primary children represent other abstract concepts in the natural sciences, such as light or photosynthesis?

References

Albert, E. (1978). Development of the concept of heat in children. *Science Education, 62* (3), 389-399.
Brooks, M. (2009). Drawing, visualisation and young children's exploration of "big ideas". *International Journal of Science Education, 31* (3), 319-341.
Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences, 14* (2), 161-199.
Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational Researcher, 32* (1), 9-13.
Cohen, L., Manion, L., & Morrison, K. (2011). *Research methods in education* (7 ed.). Milton Park, UK: Routledge.
Erickson, G. L., & Tiberghien, A. (1985). Heat and temperature. In R. Driver, E. Guesne & A. Tiberghien (Eds.), *Children's ideas in science* (pp. 52-84). Milton Keynes, UK: Open University Press.
Friedman, W. J. (2001). The development of an intuitive understanding of entropy. *Child Development, 72* (2), 460-473.
Glynn, S. M. (1989). The teaching with analogies model. In K. D. Muth (Ed.), *Children's comprehension of text: Research into practice* (pp. 185-204). Newark, DE: International Reading Association.
Haglund, J., & Jeppsson, F. (2012). Using self-generated analogies in teaching of thermodynamics. *Journal of Research in Science Teaching, 49* (7), 898-921.
Haglund, J., Jeppsson, F., & Andersson, J. (2012). Young children's analogical reasoning in science domains. *Science Education, 96* (4), 725-756.
Howe, C. (1998). *Conceptual structure in childhood and adolescence: The case of everyday physics*. London, UK: Routledge.
Howe, C., Tolmie, A., Greer, K., & Mackenzie, M. (1995). Peer collaboration and conceptual growth in physics: Task influences on children's understanding of heating and cooling. *Cognition and Instruction, 13* (4), 483-503.
Ivarsson, J., Schoultz, J., & Säljö, R. (2002). Map reading versus mind reading. In M. Limón & L. Mason (Eds.), *Reconsidering conceptual change: issues in theory and practice* (pp. 77-99). Dordrecht, the Netherlands: Kluwer Academic.
Lautrey, J., & Mazens, K. (2004). Is children's naive knowledge consistent? A comparison of the concepts of sound and heat. *Learning and Instruction, 14* (4), 399-423.
Lemke, J. L. (1990). *Talking science. Language, learning and values*. Norwood, NJ: Ablex.
Mason, L., & Sorzio, P. (1996). Analogical reasoning in restructuring scientific knowledge. *European Journal of Psychology of Education, 11* (1), 3-23.
May, D. B., Hammer, D., & Roy, P. (2006). Children's analogical reasoning in a third-grade science discussion. *Science Education, 90* (2), 316-330.
Mozzer, N. B., & Justi, R. (2012). Students' pre- and post-teaching analogical reasoning when they draw their analogies. *International Journal of Science Education, 34* (3), 429-458.
Newman, G. E., Keil, F. C., Kuhlmeier, V. A., & Wynn, K. (2010). Early understandings of the link between agents and order. *Proceeding of the National Academy of Sciences of the United States of America, 107* (40), 17140-17145.
Paik, S.-H., Cho, B.-K., & Go, Y.-M. (2007). Korean 4- to 11-year-old student conceptions of heat and temperature. *Journal of Research in Science Teaching, 44* (2), 284-302.
Piaget, J. (1932). *The moral judgement of the child*. London, UK: Kegan Paul.
Piaget, J., & Garcia, R. (1977). *Understanding causality*. New York, NY: The Norton Library.
Piaget, J., & Inhelder, B. (1975). *The origin of the idea of chance in children*. London, UK: Routledge & Kegan Paul.

Rosebery, A. S., Ogonowski, M., DiSchino, M., & Warren, B. (2010). "The coat traps all your body heat": Heterogeneity as fundamental to learning. *Journal of the Learning Sciences, 19* (3), 322-357.

Schoultz, J., Säljö, R., & Wyndhamn, J. (2001). Heavenly talk: Discourse, artifacts, and children's understanding of elementary astronomy. *Human Development, 44* (2-3), 103-118.

Sfard, A. (1998). On two metaphors for learning and the dangers of choosing just one. *Educational Researcher, 27* (2), 4-13.

Shultz, T. R., & Coddington, M. (1981). Development of the concepts of energy conservation and entropy. *Journal of Experimental Child Psychology, 31* (1), 131-153.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

White, R., & Gunstone, R. (1992). *Probing understanding*. London, UK: The Falmer Press.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17* (2), 89-100.

Received: *June 12, 2014*   Accepted: *September 18, 2014*

Jesper Haglund *(Corresponding author)*	Ph.D., Post Doc, Linköping University, Department of Social and Welfare Studies (ISV), Campus Norrköping, SE-60174 Norrköping, Sweden. Uppsala University, Department of Physics and Astronomy, Box 516, SE-75120 Uppsala, Sweden. E-mail: jesper.haglund@physics.uu.se Website: http://www.physics.uu.se/en/page/didaktik
Fredrik Jeppsson	Ph.D., Post Doc, Linköping University, Department of Social and Welfare Studies (ISV), Campus Norrköping, SE-60174 Norrköping, Sweden. E-mail: fredrik.jeppsson@liu.se Website: http://www.isv.liu.se/teknad?l=sv
Johanna Andersson	Ph.D. Student, Linköping University, Department of Social and Welfare Studies (ISV), Campus Norrköping, SE-60174 Norrköping, Sweden. E-mail: johanna.andersson@liu.se Website: http://www.isv.liu.se/teknad?l=sv