ISSN 1648-3898

STUDENT TEACHERS' REASONING PATTERNS WHILE SOLVING A CONTEXTUALIZED TASK ON THERMAL PHENOMENA

Abstract. *In this study three different patterns of reasoning have been identified: linear, star and combined reasoning. As six student teachers were working on a contextualized task on heat and temperature they showed these different patterns of reasoning during an interview situation. The data was analysed using reasoning maps. The patterns are also discussed in relation to the students' subject matter knowledge in this specific area. There are indications that the reasoning pattern is dependent on what kind of scientific subject matter knowledge the student reveals. Star and combined reasoning make it possible to look at the task from different angles and thereby develop fragmented knowledge into more comprehensive knowledge.*

Key words*: science education, thermal phenomena, interview.*

Karin Stolpe & Helge Strömdahl
Linköping University, Sweden

Karin Stolpe, Helge Strömdahl

Introduction

Students' understanding of heat and temperature is a well studied area in science education research (e.g. Albert, 1978, Engel Clough & Driver, 1985, Erickson, 1979, Erickson, 1980, Lewis & Linn, 1994, Wiser & Amin, 2001). Students' own ideas have been shown to be very stable (Driver et al., 1985) which could possibly explain why even students at higher levels show conceptual difficulties in the area of thermal physics. There are indications that pre-service teachers expect their pupils to have the same conceptual difficulties with temperature and heat as themselves (Frederik et al., 1999). This may indicate that the pre-service teachers are aware of conceptual difficulties among pupils. But do teachers have enough knowledge to guide students? Galili and Lehavi (2006) have shown that Israeli high-school teachers have problems defining concepts in physics like heat, temperature, energy etc., even though they find it important to be able to give definitions.

Early models of conceptual change suggest that students' everyday knowledge could be replaced by scientific knowledge under the right circumstances (e.g. Posner et al., 1982). In contrast to this, Gómez Crespo and Pozo (2004) propose that the process of conceptual change is much more complex and that it is necessary to find out the principles on which students' conceptions are based. The development of conceptual knowledge is highly dependent on reasoning, since ideas get real value for the student if a personal construct of the concept has occurred (Rozier & Viennot, 1991). Deep subject matter knowledge can lead to a more sophisticated way of reasoning. According to Hung and Jonassen (2006) "reasoning causally enables us to predict, infer, and explain the events or phenomena that we encounter or observe" (p. 1602).

The use of the term *reasoning* refers to the cognitive process when a person reasons about a target (Schönborn & Anderson, 2006); in this case a physics problem. Students reason with their conceptual knowledge. Reasoning is a dynamic process while the conceptions are seen as static in Schönborn and Anderson's definition. However, in this article both reasoning and conceptions are seen as dynamic. Both may change since the reasoning process may affect the conceptions. The reasoning refers to what a person is saying or doing (e.g. gestures) and therefore the dialogue serves as a tool to study reasoning. The conceptualization of reasoning in this study is also related to problem solving. Reasoning is often connected to some kind of activity, for example problem solving or laboratory work (Lemke, 1990). Conventional models of reasoning are, according to Syverson (1998), the chain of linear logic and circular reasoning. Syverson has described different alternative reasoning patterns. Among those is star reasoning which is explained as reasoning radiating outwards from a single point. This means that a statement or a fact constitutes the starting-point and from there different statements or solutions are tested.

University students' reasoning in thermodynamics is described by Rozier and Viennot (1991). They show that thermodynamics involve multi-variable problems and that students have difficulties in dealing with these. Tasks in which students have to consider more than two variables at the same time tend to be reduced into fewer variables. Rozier and Viennot describe three different ways in which reduction may take place: (i) the student can ignore some of the variables, (ii) the student can combine two variables and treat them as one, or (iii) the student handles single-variable dependences with a lack of symmetry in implications, i.e. students accept the common implication "decrease of volume leads to increase of pressure" but the reverse is seldom applied: "increase of pressure leads to decrease of volume". When students ignore variables, they often reason in linear chains about multivariable problems and this may lead to ad hoc arguments and inconsistencies (Viennot, 1997/1998). Logic and chronology are important factors of causal linear reasoning. The causality in an explanation by a student implies both logical and chronological content.

Aim

The aim of this study is to describe individual student teachers' reasoning patterns with a specific problem connected to heat and temperature. The research questions are: What types of reasoning patterns can be identified? What scientific subject matter knowledge is revealed through different patterns of reasoning about a specific task?

Methodology of Research

Six natural science teacher students attending a teacher training program at a university for Swedish secondary compulsory school (school year 7-9; pupils aged 13-15 years) were selected for interviews. During one and a half years of science studies, given for teacher students only, the students have studied different phenomena related to heat and temperature. They have also taught the concepts of heat and temperature during teacher practice.

The teacher students participated in three identical tests during their science studies. The aim was to test the student teachers' conceptual knowledge of heat and temperature. According to their levels of improvement from the first test to the second one, six students were chosen for interviews. The sample was made to get optimal variation. John and Maria showed low levels of improvement, Peter and Lars had average levels and Sara and Anna had high levels of improvement (all names are coded). Audio- and video-taped interviews were made after the third test and were transcribed verbatim. The interviews were semi-structured and the students were asked to

ISSN 1648–3898

reflect on their own answers from all three tests and were challenged to explain their thoughts and reasoning. One specific question was chosen for analysis of reasoning patterns since it generated more talk than the other. This question, taken from the multiple-choice test, reads:

> Amy took two glass bottles containing water at 20°C and wrapped them in washcloths. One of the washcloths was wet and the other was dry. 20 minutes later, she measured the water temperature in each. The water in the bottle with the wet washcloth was 18°C; the water in the bottle with the dry washcloth was 22°C. The most likely room temperature during this experiment was: a. 26°C, b. 21°C, c. 20°C, d. 18°C. (Yeo & Zadnick, 2001)

Possible solutions to the task

As a starting point for solving this task, it is possible to take either the bottle with the wet washcloth or the bottle with the dry washcloth. An important point to make is that thermal equilibrium is not reached during the 20 minutes. To take the bottle with the dry washcloth is probably the easiest starting point since the temperature of the room has to be higher than the temperature of the water in this bottle. This is the only way for the water to raise its temperature since it has no contact with other objects that could influence the temperature. You have to know that heat is transferred from an object with a higher temperature (in this case the air of the room) to an object with lower temperature (in this case the water of the bottle). The fact that the bottle is wrapped in a dry washcloth only slows down the equilibrium process, as it functions as an insulator. The washcloth itself could not lead to any change in temperature.

Another starting point is to consider the bottle with the wet cloth, which may be a little bit more complicated. Here you have to be aware of the mechanisms behind evaporation and in what way evaporation is connected to temperature changes. Evaporation is a process that needs energy. This energy will be taken from the water in the bottle and causes the temperature to decrease.

The problem is also special since the known temperatures of both the bottles are variables and the temperature of the room, which is asked for, is constant. Usually a physics problem is constructed the other way around: constants are mostly known and the variables are asked for. Since the problem requires demanding considerations it could be characterized as a multi-variable problem (Rozier & Viennot, 1991).

Analysis

The analysis started by locating the first starting point of the reasoning among the respondents. Statements made by the student and the interviewer were organized in a *reasoning map* where chronology was considered (see appendix 1). The reasoning map is a method which builds on concept maps (Novak & Cañas, 2005), but instead of putting just one concept word in each square, a whole statement is used. Different statements are then connected by arrows which indicate the chronology of the statements and thereby give a graphical picture of the reasoning process which is not attained with concept maps. The statements led to an ending point, which could be described as the end of the reasoning. The starting and ending points were highlighted in the reasoning map. In a reasoning map transcriptions are synthesised into statements which outline the meaning of one or several sentences made by the student. Reasoning maps have been used to characterize students' hypothesis-testing behaviour when they are working in a laboratory session during one semester (White, 2004). Reasoning is then seen as a process which continues throughout the whole semester. However, in this study, the reasoning process only lasts for minutes but still there are similarities with the reasoning map of White. In appendix 1 an example is given of how a transcription was transformed into a reasoning map.

The reasoning maps revealed certain graphical patterns of reasoning. The second step of the analysis aimed to describe the student teachers' personal engagement in the reasoning process. When the patterns were outlined, the reasoning maps were analysed from the aspect of who drives the reasoning process. The student him/herself, or the interviewer, may be the initiator of the reasoning process and the interviewer has an important role, since the questions or statements posed influence the student's reasoning. The character of the reasoning is dependent on who drives the reasoning process.

The third step of the analysis aimed to outline the connections between the reasoning patterns and scientific subject matter knowledge. Statements which led to new insights or statements important for the rest of the reasoning were identified and valued, according to the scientific solution. A change of starting point, conclusion and ending point made by the student teachers were also noted.

Results of Research

Patterns of reasoning

As the reasoning maps from the six student teachers were compared, it was obvious that they followed certain patterns. The first identified pattern of reasoning is called *linear reasoning* and has similarities with Viennot's (1997/1998) description. The second one is called *star reasoning* and could be compared with the pattern described by Syverson (1998). Linear and star reasoning were also combined by some students to a third pattern, here termed *combined reasoning*.

Linear reasoning

Linear reasoning starts from a statement or a question. The student teacher builds on this statement by adding new statements, without returning to the original statement. When the statements have reached a certain point the student may come to a conclusion. Sometimes the student does not have enough subject matter knowledge to make the statements needed to come to a conclusion. This study shows that the student needs help from the interviewer to structure the problem to use his/her subject matter knowledge. Sometimes the student made a conclusion out of statements that are scientifically incorrect.

Figure 1 shows a reasoning map of Lars' reasoning process and the graphical structure reveals that the pattern could be described as linear reasoning. From that linear reasoning Lars concluded that the temperature of the room was 18°C. The conclusion he made, in this case, was not equal to the ending point of the reasoning process since he continued to reason after the conclusion due to questions from the interviewer. The decision to carry on did not come from Lars himself, since he was satisfied with his conclusion, but from the interviewer. When Lars was challenged by questions from the interviewer, he showed that he had enough knowledge to reach the scientifically correct conclusion. The conclusion which he drew by himself still remained strong thus, as demonstrated by the following quotation, in which he is not totally convinced of which answer is correct:

> L: in that case it [the temperature of the water in the bottle with the wet washcloth] must have been decreasing because it's colder, but then it's illogical with that one [the bottle with the dry washcloth] so I guess it is twenty-six.

ISSN 1648–3898

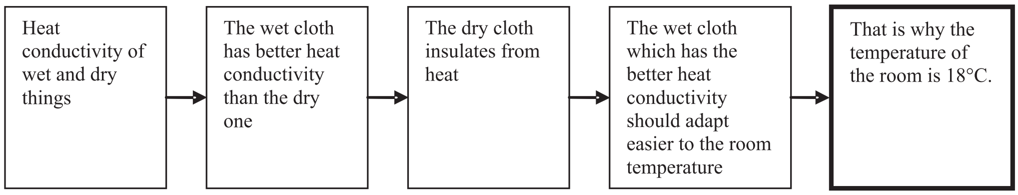


Figure 1. **Lars' reasoning follows a linear pattern. From the starting point to the conclusion there are no loops or returns. The conclusion is not the ending point of this reasoning process since the interviewer poses a question which encourages Lars to continue.**

Star reasoning

Star reasoning starts from a main statement made by the student teacher. The student returns to this statement several times during the reasoning process and connects arguments to confirm or contradict the statement. A graphical illustration of this kind of reasoning looks like a star, hence the name (see appendix). If the statement does not prove to be navigable the student may test another statement and start another line of star reasoning from this new statement. This transition may go through linear reasoning. When there are enough arguments to confirm the statement the student is ready to draw a conclusion.

Peter started his reasoning process on evaporation. He explained that water cools when it evaporates and this is the reason why the temperature decreases in the bottle with the wet cloth wrapped around it. But he doubted that the temperature in the other bottle could increase to such a degree and therefore he reasoned that the temperature closest to the temperature in the bottle with the dry cloth must also be the room temperature. He stated that the dry cloth could neither increase nor decrease the temperature of the water in that bottle, and this became the first hub of star reasoning (appendix 1). But as he deepened his reasoning on what actually happened to the bottle with the dry cloth he adds that the only thing the dry cloth can do is to insulate the bottle and thereby delay heating. This led to Peter's second hub – that the room temperature is 26°C – a hub that finally made him come to that conclusion. As Peter was the initiator of reasoning himself he was also convinced of his conclusion:

> P: Yes of course, it has to be twenty-six degrees, it was twenty-two degrees [in the bottle with the dry cloth], I have thought backwards, hm okay, I think that I stumbled, on myself there, yes okay, it was twenty-six degrees, yes, because it cannot rise from, from just the cloth.

Combined reasoning

The student teachers did not use only linear nor star reasoning but they also combined these patterns in the same reasoning. For example, in star reasoning the student may shift between two hubs via linear reasoning.

Sara used both linear and star reasoning dealing with the task. From the beginning she assumed that both bottles were held by a person which caused heat transfer from the hand of that person. Linear reasoning led her to the conclusion that the temperature of the room was 20°C. This starting point misled her reasoning and the interviewer challenged Sara to take her starting point from bottles standing on a bench. She admitted that the rise of temperature in the bottle with the dry cloth ought to be caused by a higher room temperature, because the washcloth could not contain any heat itself. This fact is something she came back to twice during her reasoning and this statement can thereby be characterized as a hub in star reasoning. The loops are thus very wide and one statement leads to the next, which is the character of linear reasoning. The ending point was a bit vague, which may be caused by the fact that she was not the initiator of the reasoning process all the time. She ended by saying:

> S: So if one is thinking that the washcloth could not contain any heat, it should have been twenty-six around [in the air], to become twenty-two in this [the bottle with the dry cloth].

The results from Maria's reasoning indicate that it is important that the student is well skilled in language. Maria was not born in Sweden and has Swedish as her second language. As the transcriptions were transformed into a reasoning map it became clear that she had misinterpreted the question, as the following quote shows:

> M: The water in the bottle was twenty degrees and the dry cloth was twenty-two and then, well the water that was there must have been… a little warmer since the cloth… eh, maybe was cooled down by the water and hence it became twenty-two.

The starting and ending points

The starting point is of importance since subsequent reasoning builds on it. A starting point which leads the reasoning process in the wrong direction is difficult for a student to correct. Anna chose a starting point which proved to be insurmountable. She assumed that the temperature had increased by just as many degrees in the bottle with the dry washcloth as decreased in the bottle with the wet one, and so she concluded that the room temperature must be 20°C. Anna ended up in a blind alley as she admitted that the temperature of 22°C in one of the bottles could not be reached when the room temperature was 20°C, as she had proposed. John, on the other hand, started from a statement that also turned out to be his conclusion: the temperature must be higher then 22°C in the room since it is the only way to raise the temperature in one of the bottles. He did not take into account the bottle with the wet wash cloth, as the following quote illustrates:

> J: The dry washcloth insulates, you know, and then… But why would it be… But why would it? If it was twenty degrees and then it became, yes… Yes, here I think like this, here I feel that it would be twenty-six degrees because I don't know why the water should be warmer than the temperature of the room.

The ending point does not have to be the same point as when the student reaches a conclusion. Lars states his conclusion early as he says:

> L: The wet cloth, which is the best conductor of heat, should in that case have adapted to the room… to the temperature of the room best. That is why I write eighteen.

As the interviewer continues to pose questions Lars is forced to carry on:

> I: What about this dry washcloth?
> L: Yes it is strange if it can raise the temperature.
> I: Mm.
> L: Is it…? [laughs] but I don't have an explanation for that because it does not correspond… there are a lot of things that don't correspond… my reasoning should fail totally if it was a higher temperature than… why does the wet cloth become eighteen [degrees]? I say that it does not correspond.
> I: What happens to the wet cloth then?
> L: Yes it conducts… heat better.

ISSN 1648–3898

> I: But if you don't think of conduction, well if you think, what happens to a wet cloth that is in a room?
> L: Well, it will adjust to the temperature of its surroundings.

Lars shows no evidence of picking up the new ideas in his reasoning. His knowledge is fragmented and finally he reaches a point where he explains his uncertainty about the answer and then asks if it is possible to move on to the next question. The ending point of the reasoning is reached:

> L: This was really messy. I know that I thought on this every time [as I was doing the tests]. Should we go on to the next one [next question]?

Peter's ending point, on the other hand, coincides with his conclusion. He states that the temperature must be twenty-six degrees in the room. He says: *Okay, now I am on.* Then he goes on and reads the next question. The same is true for Anna, Sara and John.

Connecting patterns of reasoning to subject matter knowledge

Linear reasoning

As the starting point of Lars's reasoning on heat conductivity was irrelevant, it became problematic for him to come to the correct conclusion, unless the starting point was changed. Lars was not willing to let go of the statement and the linear reasoning pattern shows this clearly. Even when his conclusion was questioned by the interviewer, he refused to give up his conclusion (see quote above). However, the answers to the questions thus revealed that Lars had the knowledge to reach the correct conclusion. It is not a matter of poor subject matter knowledge since he thought that it was strange that the temperature of the water in the bottle with the dry cloth could rise if the temperature of the room was 18°C. He also said that evaporation lead to cooling and that energy was needed for the water in the wet cloth to evaporate. Lars' knowledge was rather fragmented than poor. The ending point was built upon the answers which came out of the questions from the interviewer, as if Lars wanted to please her. In spite of that, the ending point was not Lars' own conclusion since he was not totally convinced of the answer, by stating:

> L: It is either eighteen or twenty-six if you just look at this so… yes.
> I: So you mean that it [the temperature] can rise from eighteen?
> L: No, in that case it [the temperature] has dropped because it is colder but then this is not logical with that one [the bottle with the wet washcloth] so I guess it is twenty-six… [laughs] this was really messy. I thought of it every time, I know that. Could we go on to the next one?"

As John started with a scientifically correct statement there was no reason for him to develop his ideas. He said that the water in the bottle with the dry washcloth could not be warmer than the room temperature and therefore the statement supported his conclusion. Linear reasoning is not possible to prove in such a short reasoning process. John did not come back to one statement several times. There was a straight line from the starting point, via the statement, to the conclusion. Nothing revealed if John was aware of the effect of evaporation in the bottle with the wet cloth and it is hard to validate his scientific knowledge. With further questions from the interviewer this could have been clarified.

Star reasoning

Peter's star reasoning helped him to question his own statements. As he concluded that the dry cloth could neither increase nor decrease the temperature in the water of the bottle, it could only make the process go slower, he realised the room temperature had to be 26°C. Peter was building his reasoning on scientifically correct statements and he was aware of and took into account the effect of evaporation on the wet washcloth. Peter also took into account the time factor, which became important for him, because if the experiment had continued, the temperature in the bottle with the dry cloth would have been even higher. Since Peter was validating his conclusion he was able to find weaknesses and strengths in his own statements. The conclusion thus builds on a more rigid argumentation.

Combining linear and star reasoning

Sara had a central statement which she returned to several times in her reasoning:

> S: The [dry] washcloth cannot hold any heat in itself.

From a scientific point of view this may seem curious but as one takes a look at the reasoning which leads to this statement, it is clear that the statement is a paraphrase of the first law of thermodynamics: energy could not be created nor destroyed, but only transferred. Sara said that the rise of temperature in the bottle with the dry cloth ought to be a consequence of the temperature of the room because *the* [dry] *washcloth could not have any heat in itself*. This statement was so important to Sara that she returned to it twice, and it was also decisive in her final conclusion. Star reasoning out of a correct central statement helped her question her own thoughts and to validate her statement from different angles.

Anna's starting point was that the temperature changes two degrees in each direction in the two bottles. As she was testing her hypotheses she realised that this statement implied that the temperature in the bottle with the dry cloth increased and this made her challenge her own reasoning. Through linear reasoning Anna concluded that the only way for the temperature to rise in one of the bottles is by the room having a higher temperature. She then tried to explain why the bottle with the wet washcloth had decreased in temperature, and came up with the statement that heat is transferred from the water inside the bottle to the washcloth to make evaporation from the wet cloth possible. She also added that heat of the room is involved in the process. The fact that Anna was open to change her starting point, and thereby use another set of ideas to build on, helped her in reaching the correct conclusion.

Discussion

The *reasoning maps* used in the analyses of the empirical data gave a graphical picture of the students' reasoning which helped characterize different patterns. This study describes three different patterns of reasoning on a thermal assignment: *linear reasoning*, *star reasoning* and *combined reasoning*. Linear reasoning, could be compared with the linear reasoning described by Viennot (1997/1998). Star reasoning, which is theoretically described by Syverson (1998), has been proved empirically in this study. The combination of these two reasoning patterns is the third pattern, combined reasoning, and not reported before in science education research.

All reasoning has a starting point. Why the students chose one starting point and not another may be caused by recognition of the problem type or by how the student perceives the situation. Since all the student teachers had different starting points it is not the problem itself that indicates how to solve it. As a student starts from a misleading starting point it is demanding to come up with a new one. Lars failed to leave his first conclusion, originating from a starting point of heat

ISSN 1648–3898

conductivity. This may have been dependant on his linear reasoning; or as an alternate explanation, the failure to find another starting point generated a linear reasoning pattern. Both Anna and Sara managed to find new ways of reasoning, most likely revealed by combining linear and star reasoning. Analogically to the argument of linear reasoning it was possible for Anna and Sara to find a new start which led to the combined reasoning pattern.

As the starting point will influence reasoning it will also impact the ending point. Anna, Sara, John and Peter had ending points which coincided with the conclusion, which means that the conclusion also is the ending point of reasoning. Even though Sara was not quite sure of her conclusion, her conclusion coincided with the ending point. Anna, Peter and John took the initiative in their reasoning and are thereby convinced of their conclusions. The conclusions became obvious ending points. In Lars' case, on the other hand, the conclusion did not coincide with the ending point. After stating his conclusion Lars did not want to go on reasoning. This result may indicate that when a student reaches a conclusion there is no need to go on testing it and looking at the problem from different angles. This behaviour is encouraged in the school context and is thereby the most likely. The ending point is thus something other than the conclusion and it is important to keep these concepts apart. The role of the interviewer is probably crucial for the outcome of the reasoning and this would be interesting to investigate further.

Linear reasoning may prevent the student from coming up with important ideas, which are needed to reach a scientifically correct conclusion. It may also be more likely for the student teachers to make any of the reductions of variables suggested by Rozier and Viennot (1991), if the reasoning is linear. Since the student does not come back to a statement, looking at the problem from another angle, it is probably easier to forget about variables or combine several variables and treat them as one, just as Rozier and Viennot have observed. This study confirms Rozier and Viennot's results, in this aspect. It is also possible to turn this line of argument inside out by claiming that certain subject matter knowledge may entail a certain pattern of reasoning.

One way to get around the reductions of multi-variable problems is by using star reasoning, since here the student is able to look at the problem from different angles and it is also possible for him/her to find a lack of logic or symmetry in the reasoning. Through star or combined star and linear reasoning, the student has to reveal his/her subject matter knowledge, just as Peter, Sara and Anna did. As the subject matter knowledge is expressed, it is also available for elaboration. This helps the student teachers to question and validate their statements. If the statements do not fit together logically the starting point may be reconsidered. Star reasoning is one way for the student teachers to develop his/her subject matter knowledge. By connecting fragmented building blocks of knowledge, the personal subject matter knowledge becomes more comprehensive.

In the area of heat and temperature this kind of multi-variable problem is common and causes difficulties for students. To study reasoning and analysing what statements students are using to draw conclusions can then be important in the understanding of the complex process of learning and understanding science as Gómez Crespo and Pozo (2004) refer to. When a student uses star or combined reasoning s/he also has to confront her/his own ideas and thereby construct new ideas. As suggested (Rozier & Viennot, 1991), it is likely that the new ideas will be more resistant if they are personally constructed. This process was shown by both Peter and Anna, since they both had different answers from the beginning but ended up convinced that they now had made a correct interpretation of the problem. Since Peter and Anna were also the initiators of the dialogue they were convinced of their conclusion, as distinct from Sara and Lars who showed some uncertainty. The lack of personal construction (Rozier & Viennot, 1991) may be the cause of this uncertainty.

Student teachers should be made aware of the quality of different reasoning patterns and the possibility that different reasoning patterns have different consequences for problem solving. This knowledge would be useful for enhancing professional teaching in meetings between teacher and pupils. The reasoning patterns identified in this study all have their specific significance when solving a contextualized thermal problem.

References

Albert, E. (1978). Development of the concept of heat in children. *Science Education*, 62, 389-399.

Driver, R., Guesne, E. & Tiberghien, A. (1985). Children's ideas and learning of science. In: R. Driver, A.G. Harrison & A. Tiberghien (Eds.), *Children's ideas in science*, (pp. 1-9). Milton Keynes, Philadelphia: Open University Press.

Engel Clough, E. & Driver, R. (1985). Secondary students' conceptions of the conduction of heat: bringing together scientific and personal views. *Physics Education*, 20, 176-182.

Erickson, G.L. (1979). Children's conceptions of heat and temperature. *Science Education*, 63, 221-230.

Erickson, G.L. (1980). Children's viewpoints of heat: a second look. *Science Education*, 64, 323-336.

Frederik, I., Van Der Valk, T., Leite, L. & Thorén, I. (1999). Pre-service physics teachers and conceptual difficulties on temperature and heat. *European Journal of Teacher Education*, 22, 61-74.

Galili, I. & Lehavi, Y. (2006). Definitions of physical concepts: A study of physics teachers' knowledge and views. *International Journal of Science Education*, 28, 521-541.

Gómez Crespo, M.Á. & Pozo, J.I. (2004). Relationships between everyday knowledge and scientific knowledge: understanding how matter changes. *International Journal of Science Education*, 26, 1325-1343.

Hung, W. & Jonassen, D.H. (2006). Conceptual understanding of causal reasoning in physics, *International Journal of Science Education*, 28, 1601-1621.

Lemke, J. L. (1990). *Talking Science. Language, learning and values.* Norwood, New Jersey: Ablex Publishing Corporation.

Lewis, E.L. & Linn, M.C. (1994). Heat energy and temperature concepts of adolescents, adults, and experts: implications for curricular improvements. *Journal of Research in Science Teaching*, 31, 657-678.

Novak, J.D. & Cañas, A.J. (2005). The theory underlying concept maps and how to construct them. Florida Institute for Human and Machine Cognition. Available at http://cmap.ihmc.us/Publications/ResearchPapers/TheoryUnderlyingConceptMapsHQ.pdf.

Posner, F.J., Strike, K.A., Hewson, P.W. & Gertzog, W.A. (1982). Accommodation of a scientfic conception: Toward a theory of conceptual change. *Science Education*, 66, 211-227.

Rozier, S. & Viennot, L. (1991). Students' reasoning in thermodynamics. *International Journal of Science Education*, 13, 159-170.

Schönborn, K.J. & Anderson, T., R. (2006). A model of factors determining students' ability to interpret external representation in biochemistry NARST (National Association for Research in Science Teaching) San Francisco, CA, United States.

Syverson, M.A. (1998). Patterns and process of reasoning in virtual worlds. In: C. Landauer & K. Bellman (Eds.) *Virtual Worlds and Simulation Conference* (VWSIM '98). (pp. 107-112). San Diego, Society for Computer Simulation International.

White, B. (2004). Reasoning Maps: a generally applicable method for characterizing hypothesis-testing behaviour. *International Journal of Science Education*, 26, 1715-1731.

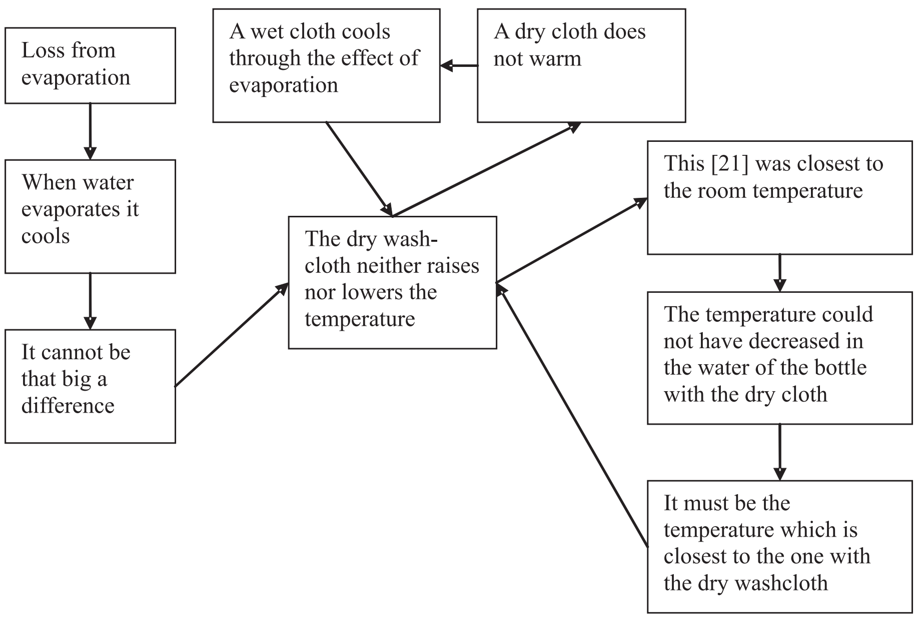
Viennot, L. (1997/1998). Experimental facts and ways of reasoning in thermodynamics: learners' common approach, In: A. Tiberghien, E.L. Jossem & J. Barojas (Eds.) *Connecting research in physics education with teacher education* (C3). International commission on physics education.

Wiser, M. & Amin, T. (2001). "Is heat hot?" Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena. *Learning and instruction*, 11, 331-355.

Yeo, S. & Zadnik, M. (2001). Introductory thermal concept evaluation: Assessing students' understanding. *The Physics Teacher*, 39, 496-504.

Appendix 1

Peter: I, here I have thought on the loss from evaporation on the third… when water evaporates it cools and it was… the water with the wet washcloth was 18 degrees and the dry one was 22 degrees… [reads]: room temperature… Well, I am simply thinking that it cannot be that big difference because the dry washcloth neither raises nor sinks the temperature [Interviewer: mm] it does not warm – a dry cloth, but on the other hand wet cools [I: mm] through the effect of evaporations so the dry cloth neither raises nor sinks the temperature. This was closest to the temperature of the room it was, it could not have sinken… eh, I mean, heh ehm, the temperature could not have [reads]: most likely room temperature… it could not have cooled down either I thought, well so I took the one which was closest to the one with the wash cloth because it does not happen anything there.



The figure shows a *reasoning map* created from one part of the transcript of Peter's reasoning. The figure should be read in the direction of the arrows and from left to right. This is an example of a star reasoning.

Received 10 August 2007; accepted 30 November 2007.

Karin Stolpe	Ph.D. Student at Department of Social and Welfare Studies Swedish National Graduate School in Science and Technology Education Research (FontD), Linköping University, S-601 74 Norrköping, Sweden E-mail: karin.stolpe@isv.liu.se
Helge Strömdahl	Professor at Department of Social and Welfare Studies Swedish National Graduate School in Science and Technology Education Research (FontD), Linköping University S-601 74 Norrköping, Sweden. E-mail: helst@isv.liu.se