Learning in Science and Mathematics
The LISMA group

Student teachers use of models when explaining everyday phenomena in physics

Andreas Redfors and Ingemar Holgersson, Kristianstad University, Sweden

Working paper presented at:

NARST – ANNUAL MEETING 2006
April 3 - 6, 2006, San Francisco, USA

Introduction

A central feature of teachers' competence is the ability to illuminate and explain the objects of teaching. It has been widely suggested that learning in science is influenced by views about the nature of scientific knowledge and of scientific models (Craven et al., 2002; Elby & Hammer 2001, Justi & Gilbert, 2002: Ryder & Leach 2001, Songer and Linn, 1991; Tiberghien & Megalakaki 1995, Treagust et al. 2002). Hence, student teachers need to develop their view on the relationship between scientific theories and the real world, i.e. the epistemology of their subject matter. We will discuss this in this paper in terms of models and modelling in science teaching. The process of acquiring an operational view of this for future science teachers is concluded to require a long time (Justi & van Driel, 2005), several years. The teacher education in Sweden makes it possible to elaborate on this since it is a 4.5 year education, and subject matter and professional development are mixed throughout.

As an exploratory study in this area this paper examines student teachers' use of scientific models in explanations of phenomena involving matter and transformation of matter. Key interests informing the design are the context dependence of the models drawn upon by students, and whether students use more than one explanatory model in a given context. We base our understanding of models on the presentation by Giere (1997) in a book about scientific reasoning. Several authors suggest that students simultaneously use a range of explanatory models (Engel Clough & Driver, 1986; Galili & Hazan, 2000; Petri & Niedderer, 1998; Redfors & Niedderer, 2004; Redfors & Ryder, 2001; Taber, 2000; Tytler, 1998). Different theoretical explanatory models can be used either during one single explanation of a given phenomenon and context, or context dependently during explanations of related phenomena, or during explanations of one phenomenon in different contexts, e.g. writing, talking, drawing a picture. The explanatory models can be scientific models or variation there of established during a teaching and learning process (Coll, France & Taylor, 2005; Crawford & Cullin, 2004; Petri & Niedderer, 1998). We allow for individual variations, and variations for a given individual. In this paper we are looking for constituents of scientific models in student explanations.

Another question addressed is if students' ontological views of these explanatory models differ for different phenomena, and if there is a progression, or notable change, of this over the years of the teacher education program. We are asking the students to explain, in different ways, three different phenomena. Two scientifically advanced and one more straightforward.

Methods and Sample

We report on student teachers' explanations of three different phenomena, a burning candle, a gas flame and a bottle with heated air confined by a balloon, see Figure 1. The students were asked to explain and compare processes, and they were asked to draw magnified pictures of each phenomenon. We were also probing for their view of the nature of scientific models. The sample is twofold. It is partly the total cohort (year 1-4) of future secondary science teachers five years ago. This group constitute a cross-sectional sample.

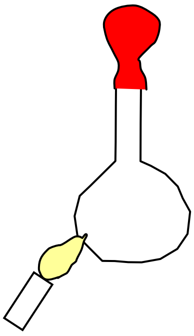


Figure 1. Air in a flask covered with a balloon.

In addition, the first year students of that year have been followed longitudinally throughout their 4½ year education, ending fall 2004. The methodology gives us an opportunity to analyse and report on the different aspects of longitudinal and cross-sectional studies, specifically the problem of comparing groups of different individuals.

The program consists of nine fulltime half-year courses, see table 1. It starts with a general course in education where all the different student teachers are given the opportunity to meet and discuss different perspectives on teaching and learning. It also includes some practice teaching.

Table 1. Overview of formation of teachers at Kristianstad, Sweden. The shade of grey indicates the degree of Science Education and/or General Education in the content of the courses.

Year 1		Year 2		Year 3		Year 4		Year 5
Education intro	Chemistry	Biology Mathematics	Education learning	Physics	Technology Mathematics	Biology	Elective science	Education teaching

This introduction is followed by courses in eligible chemistry, biology and mathematics. All science and mathematics courses are specially designed for teacher formation, and science education is a constituent. The second general semester has children and learning as the prime objective, and practice teaching for eight weeks is included. The program continues with courses in physics, technology, mathematics and biology. The students choose two science subjects in which they specialise further during their eighth semester. The last semester of the program is dedicated to the professional role, and it includes ten weeks of general education with practice teaching for 5-7 weeks, and ten weeks of writing an exam paper. The paper has to have a pedagogical/educational profile, and be based on research in science education and/or general education.

The cross sectional data were collected during semesters 1, 3, 5 and 7 after the summer break. We set the collection of data up to investigate the long term influence of the most relevant science courses for explanations of the chosen phenomena, chemistry and physics.

- Group 1: before chemistry, 15 students
- Group 3: half a year after chemistry, 22 students
- Group 5: before relevant physics, and 1½ years after chemistry, 12 students
- Group 7: half a year after physics, and 2½ years after chemistry, 26 students.

The phenomena in the survey can be explained by using a number of different explanatory models of differing degrees of sophistication. Thus the written survey was divided into two parts, with the second part distributed after completion of the first. The first part consisted of open response questions, to ensure that students were not initially guided towards any particular explanatory models. The students were asked to draw pictures, and to give detailed explanations. They were also asked to give alternative explanations. In the second part, which was given to students having completed the first part, the students were asked to give more detailed explanations, and they were guided towards a particle model of matter. They were also asked to mark agreement or disagreement with cited student statements concerning the nature of scientific models. The statements were formulated based on observations by the authors of former students during many years of teaching. For further details, see the entire questionnaire in Appendix A.

The longitudinal part of the study adheres to the definition of longitudinal studies made by White and Arzi (2005) in a recent article where also the need for further longitudinal studies in science education is stressed. The longitudinal group has answered the questionnaires twice, during their first semester and after two years, just before physics. To get reliable and detailed picture of the students views (Ryder & Leach, 2000) we interviewed a subset of the group during their last year. The interviewees were asked to give a verbal response to each of the written questions. The interviews also included demonstrations of the phenomena, i.e. the students could experimentally test their predictions, and after the experiment reflect on their explanations. The students were also shown their drawings from the two former occasions and asked to reflect and comment on differences and similarities. They were asked to meta-cognitively reflect on the drawings and we discussed how they currently thought about the drawings.

Data analysis and Results

In order to examine the details of models drawn upon by students we conducted an ideographic analysis (Driver et al., 1996). Data was analysed to reflect each student's position as written, rather than evaluated against a set of normative criteria. We began our analysis question-by-question. Working independently each of us read the same sub-sample of responses to a single question and generated provisional category sets. These were compared and reworked into a single category set, which was used to code responses to this question for the whole sample. This procedure was repeated for all the questions. Finally, we reworked the category sets for the different questions into a single general set of categories that could be applied to all questions. There are three main groups of categories, i.e. descriptions of matter, radiation and ontological positions, see Table 2.

Table 2. The categories used in the analysis of the written and oral responses.

M	**Matter**	**O**	**Ontology**
NR	**R**eaction/combustion gives heat/radiation	ON	**N**ot really exist
NS	Different **S**ubstance – diff properties	OIn	**I**mplicit **n**ot really exist
NH	**H**ot gas rises (heat rises)	OIe	**I**mplicit really **e**xist
NC	Heat/temperature gives **C**olour	OE	Really **E**xist
NL	Heat/energy ⇔ **L**ight (Radiation)	OM	**M**ore than one model can exist
ND	Heat ⇔ volume, pressure, **D**ensity	OO	**O**ne correct model only
IR	Mention chemical Reaction	OW	**W**orld of models and reality are separated
PN	Mention of particles – **N**o explanation	OR	Models belong to/represent the **R**eal world
PT	Speed of particles ⇔ heat/**T**emp/volume		
PC	Speed of particles ⇔ **C**olour	**Q**	**Qualitative/Quantitative**
PD	**D**ensity distribution of particles	QEv	Qualitative - **Ev**eryday language
PE	**E**xcited particles used	QSc	Qualitative - **Sc**ientific language
PR	Chemical **R**eaction used	QHq	**H**alf **q**uantitative (more and more)
		QQ	**Q**uantitative
B	**Balloon**	QM	**Q**uantitative **M**odelling (System thinking)
BV	Implicit or explicit **V**acuum – "sucked in"		
BN	**N**o expansion upside down	**A**	**Additional answers**
BU	**U**nequal, longer time for upside down	AD	**D**on't know
BB	**B**oth balloons just as fast	AN	Answer **N**o!
		AW	**W**ithout answer
R	**Radiation**	AA	**A**lready answered
RH	**H**eat as waves		
RL	**L**ight as waves, Radiation as light		
RP	Radiation as **P**hotons		
RC	Wavelength gives **C**olour		
REr	**E**xcited states give **r**adiation		
REl	**E**xcited states give **l**ines		

A preliminary analysis of the written responses from the first cohort - the cross-sectional study - was reported at the ESERA conference in 2003. We reported on a content dependency for the student answers. All students were using a particle model of matter at some point. However, some used a continuous model of matter for all questions except the ones where they were asked to draw a picture or explicitly asked to use small particles in their explanations. These students apparently knew about the particle model, but they did not use it spontaneously. There was no progression to be seen for the cross-sectional sample from year 1-4. One of the groups (Group 3) stood out, but we had no conclusive evidence whether it was because of the individuals in the group, or because they most recently studied chemistry, where the particle model is a central feature. In this paper we have included the data from the longitudinal sample and comparisons are made.

Descriptions of matter

Analysis of the groups

One focus is the students' descriptions of matter. What are the model constituents of their explanations? What explanatory models are used? The final categories are given in table 2, and there are three groups within the matter categories

- N: continuous or macroscopic model of matter
- I: intermediate model
- P: particle model of matter

The total number of categorised student statements is 1 244. Notice that each student's answer to a question can contain more than one categorised statement. In table 3 we show how the statements are distributed among the different matter categories.

Table 3. Number of statements categorised in the groups of the matter categories. Both cross-sectional and longitudinal results are given.

	Phenomena	N continuous	I intermediate	P particle	P/N
Group 1:1*	Flames	51	5	50	**0.9**
	Flask	48	0	45	**0.9**
Group 3	Flames	30	15	100	3.3
	Flask	62	0	83	1.3
Group 1:5*	Flames	35	6	55	**1.6**
	Flask	34	0	44	**1.3**
Group 5	Flames	51	8	26	0.5
	Flask	29	0	35	1.2
Group 7	Flames	71	14	88	1.2
	Flask	84	0	87	1.0
Group 1:8*	Flames	13	2	36	**2.8**
	Flask	10	0	27	**2.7**

* Longitudinal data

A focus of the teaching in chemistry and physics has been to elaborate on the use of particle models in descriptions of phenomena involving matter and transformations of matter. We therefore expect a progression in the use of particle models along the years, but this is not observed for the cross-sectional sample, see table 3. However, one can see other differences between the different year-groups. The second year students, group 3, are using particle models to a greater extent then the other groups, especially for the more scientifically advanced flames. The group of individuals seem to be more decisive than the number of years studied. Notice, that in a cross-sectional study it is not clear if it is the group as such, or the individuals that makes the difference. It could also be an effect of the fact that group 3 most recently studied chemistry, where the particle model is a central feature.

On the other hand, for the longitudinal sample the expected progression through the education can be seen, see table 3. A larger portion of the students are using a particle model of matter in their explanations as the years go by. It seems to us that some progression is inevitable, and therefore the longitudinal design is deemed to be more suitable for our purposes, see further discussion towards the end of this article.

When looking at the cross-sectional data for the different questions and the different phenomena we see context dependence, both concerning the phenomena and the context of the questions. In table 4 we present the categorisation of the statements in the cross-sectional data, broken down to the different questions.

Table 4. Number of statements from the cross-sectional data categorised in the main groups of the matter categories for the different questions.

	Questions	N continuous	I intermediate	P particle
Flame 1	*Why warm?*	38	16	26
	Why shine?	26	5	42
	Compare	61	0	21
	Draw picture	20	11	47
	Another explanation	10	5	10
	Do flames exist?	27	2	17
Flame 2	*Use small particles*	1	1	37
	Explain spectrum	18	0	33
	Picture of processes	2	2	31
Flask 1	*Heating flask means?*	74	0	37
	Heating upside-down?	78	0	27
	Draw picture	38	0	71
	Another explanation	7	0	14
	Does air exist?	15	0	43
Flask 2	*Use small particles*	7	0	20
	Picture of particles	4	0	38
Total		426	42	514

It can be seen that the particle model is relatively more used in explanations to some of the questions, i.e. there is a clear context dependency of students' use of explanatory models. The question about why the flames can be seen, and the one about explaining the optical spectrum are booth making the students draw on a particle model of matter. We think of this as a phenomenon based context dependence.

There is also another kind of context dependency to be seen, namely one connected to the phrasing of the questions. The students are using the particle model more extensively when asked to draw a picture, and when asked explicitly to use small particles in their explanations. This shows that the students know about the particle model, and that they can use it. Even though, they in many cases choose firstly not to do so.

Analysis of individuals

As the second to last question in the first part of the survey we asked the students if they could think of another way of explaining the phenomena than the ones used so far, see appendix A for the phrasing of the questions. There is only a small number of students doing this. For the two phenomena we have in the cross-sectional data.

Flames: 7 of the 75 students (9%) categorised as N or I, i.e. not explicitly using a particle model, who change into using a particle model for the *“Another explanation”* question.
5 students (7%) who change the other way around from P to N or I.

Flask: 8 of the 75 students (11%) categorised as N, no students categorised as I for the flask questions, who change into using a particle model for the *“Another explanation”* question.
1 student (1%) who changes the other way around from P to N.

The longitudinal data does not give much information on this. In this group they tend not to present other explanations for this question.

We were also interested to see whether the students would change their ways of explaining when going from the scientifically complicated flames to the more straightforward flask phenomenon. We have looked at the first question about the flames and the flask, “*Why warm?”* and *“Heating flask means?*”. We use these questions to get what would correspond to students' first spontaneous answers in an interview, where students tend to use the most familiar model constituents (Eskilsson, 2001). For these first questions there are the following results presented in table 5.

Table 5. Number of students that change explanatory model for the two different phenomena, from the flames to the flask.

Students' change of explanation	Cross-sectional	Group 1:1*	Group 1:5*	Group 1:8*
From I/N to P	22 (29%)	4 (27%)	3 (21%)	3 (43%)
From P to N	11 (15%)	4 (27%)	3 (21%)	0 (0%)
Staying with I/N	30 (40%)	5 (40%)	3 (21%)	0 (0%)
Staying with P	12 (16%)	1 (7%)	5 (36%)	4 (57%)

*Longitudinal data

About half of the students in the cross-sectional sample change, and use different ways of explaining the different phenomena. We see that about a third (29%) of the cross-sectional students change to a scientifically more advanced model and draw on a particle model of matter when explaining the flask phenomenon. This is not what would be expected from a physicist, given the important role of particles in the phenomena of the flames. Thus it seems that when dealing with more abstract phenomena the students adopt a less advanced explanatory model.

Notice that the longitudinal data show a clear progression through the education and more and more of them use a particle model. However some of them still use less advanced models for the more complex phenomenon, the flames. Students in group 1:1 show the same patterns as the total of the cross-sectional data, but this pattern changes for these students and in their fourth year they all end up using a particle model, even though some of them start with a continuous model for the flame.

The design of the survey allows for tests of consistency in individual student's responses. The questions present contexts where a particle model of matter could fruitfully be used in all the explanations. However, few students choose to do so. We define a consistent response to the questions as one that uses the same basic model constituents in more than one explanation. We present a few examples from our tests of consistency of the students' responses.

There are only 5 students (7%) in the cross-sectional sample who consistently use a particle model of matter in their answers for all the questions in the survey. In the longitudinal sample we have 2 students (8%) in group 1:1, 4 students (29%) in group 1:5 and 3 students (43%) in group 1:8. Thus, the percentage of students that are consistently using models increase.

Eight students in the cross sectional sample use a particle model consistently for the questions about the flames, but revert to a continuous model when discussing the behaviour of the balloon and the flask. In the longitudinal sample we have 2 students (8%) in group 1:1, 4 students (29%) in group 1:5 and 4 students (57%) in group 1:8 doing this. We believe that they struggle with explaining the behaviour of the balloon. They predict that the balloon will not expand when the flask is heated upside down, see appendix A for diagrams of the flasks. It is difficult to explain such behaviour of the balloon with a particle model of the air in the flask. Instead they base their explanations on the notion that "hot air rises".

One of the intreviewees stated that she could make a correct prediction because of the presence of experimental equipment. Earlier she had thought that the balloons would expand differently. Another changes his explanation when confronted with the fact that the balloons behave the same. He starts uses a particle model, which he has used before.

Actually 53 of the students (71%) in the cross-sectional sample predict that the balloons will behave differently in the two cases, flask heated upright and flask heated upside down, see categories BV, BN and BU in table 2. In the longitudinal sample we have 10 students (67%) in group 1:1, 7 students (50%) in group 1:5 and 1 student (14%) in group 1:8. So the percentages go down in this case for the longitudinal sample too.

Eleven of the students (15%) predict that the balloon will be "sucked into" the flask when the flask is heated upside down. The claimed reason for this is that "hot air rises" leaving no air at the place of the balloon. Four of these 11 students are in group 1:1, but only one of them remain with this prediction the next time, and non of the students predict that the balloon will be sucked in at the last occasion.

There are 38 student statements in the cross-sectional data categorised as N (continuous model) for the "*Draw picture*" question of the Flask I, see table 4. This is noticeable since most responses to the "draw" questions are categorised as P (particle model). 33 of these students predict the balloons to be expanding differently, and their drawings are categorised as BV, BN or BU, see table 2. The fact that they predict a non-physical behaviour of the balloon seems to inhibit them from using the physically appropriate particle model. They are strongly influenced by their everyday idea that hot air rises. An idea based in a continuous model of matter. This is not seen so strongly in the longitudinal data.

All the students use a particle model of matter at some point, i.e. no one is categorised as N (not I either) for all the questions. However, there are 7 students (9%) in the cross-sectional sample who are categorised as N or I for all questions except the ones where they are asked to draw a picture or explicitly asked to use small particles in their explanations. Even these students know the particle model, but they do not use it spontaneously.

Radiation

In table 2 we present the categories used for categorisation of the students' different ways of referring to models of electromagnetic radiation, especially visible light and infrared or heat radiation. Students refer to radiation in their responses to a varying extent, but two questions stand out, i.e. the two questions closely related to radiation in the Flame I section; *Why shine?* and *Explain spectrum.*

The responses to these questions show a progression among the different groups in the use of a photon model of radiation. The progression is more accentuated for the longitudinal sample. The students in Group1 are increasingly using the concept photon in their explanations as the years go by, see Table 6.

Table 6. Percentages of student statements categorised as RP (radiation as photons) for the different groups.

Group	Categorised statements	Categorised as RP	Percentage
Group 1:1*	28	6	**21%**
Group 3	49	10	20%
Group 1:5*	37	12	**32%**
Group 5	14	2	14%
Group 7	71	27	38%
Group 1:8*	32	13	**41%**

* Longitudinal sample

For the cross-sectional data we see that the students in group 7, which is the only group having studied physics, are more often using the concept photon as a part of their explanation. The longitudinal data gives a much clearer picture, with a definite increase of the percentages.

Several students struggle in their explanations, and their view of models describing electromagnetic radiation does not come out clearly. They have difficulties explaining the questions about the spectrum of the flame.

Epistemological and ontological views

The first part of the survey was concluded, both for the flames and the flask with a question about whether the flame and the air in the flask respectively really exist, see appendix A. We were interested to see whether there were any differences in the way that the students talked about air and flames. Air cannot be seen, but the students know of different uses for it. The flames on the other hand are there to be seen, but do they exist?

48 of the 75 students (64%) state that flames really exist

65 of the 75 students (87%) state that air really exists

The views on whether flames and air really exist are stable in the longitudinal sample. The view does not change over the years for any student. The fact that a majority of the students claim the air to really exist, concurs with the idea that the flask is a less abstract phenomenon, where it is probably easier for students to use an abstract explanatory model, see above and Treagust et al. (2002).

We have also looked at the students' views of the relation between reality and theoretical models. This was done in part II of the questionaire where the students were asked whether they agree or not with statements made by fellow students. The statements were chosen to challenge the students' views of the role of models in physics.

There were also statements about whether flames and air really exist, which were there to confirm the answers to the open questions in part I of the survey. All the students confirmed their asnwers to the open questions in part I by the way they agreed or not agreed with the different statements. They were consistent in their ontological views about air and flames. This also indicates that the statements were successful in extracting students' views.

The statements about models and their role in physics gave the following distribution for the categories, see table 7. Only students with a clear consistent view are included, i.e. the two statements about models gave the same categorisation, and the "not sure" answers in the middle were discarded.

Table 7. Number of students categorised in the ontological categories about models.

	Phenomena	OM More than one model	OO One correct model only	OW Models are models	OR Models are real
Group 1:1*	Flames	**8**	**1**	**4**	**11**
	Flask	**9**	**4**	**2**	**9**
Group 3	Flames	9	4	8	10
	Flask	10	5	5	15
Group 1:5*	Flames	**8**	**1**	**4**	**8**
	Flask	**8**	**3**	**2**	**9**
Group 5	Flames	5	6	2	6
	Flask	4	5	3	4
Group 7	Flames	11	10	9	14
	Flask	12	10	9	12
Group 1:8*	Flames	**6**	**0**	**7**	**0**

Flask**	**6**	**0**	**7**	**0**

* Longitudinal data

**The students were not asked explicitly about the flask in the interviews, but the students answered in general terms, with no differences indicated for the two phenomena.

As we have mentioned earlier in the case of matter there is no progression to be seen in the cross-sectional data. The students in group 7 do not give the impression of having a more sophisticated view of scientific explanations. However, the longitudinal sample is different again. For this group of students we see a progression through the education in their views about scientific explanations. There is no difference to be seen in the students' views of models for the two contexts, flames and flask. This is the same for both the longitudinal and the cross-sectional data. Another thing that comes out of the analysis is that the majority of the students do not separate between the world of models and the reality, which is in accordance with earlier research, viz. Treagust et al. (2002). However, the students in the longitudinal sample seem to make more proper distinctions during their last interview. This could be due to the fact that the teaching of physics for this group had an emphasis on the importance of separating reality and the world of theories and models.

There are only 9 students (12%) that are classified as OW and OM for both phenomena, i.e. they believe the world of models to be separate from reality and they realise that there can be more than one scientific model of importance for an explanation of a given phenomena. For the longitudinal sample we have 2 – 2 – 6 students for the tree occasions, i. e. a definite change towards the end of the education, see above.

Qualitative – quantitative

When focusing on the way the students were writing their explanations we categorised the statements according what we have called a qualitative/quantitative measure. We have used it as a measure on the students' enculturation to science (Cobern & Aikenhead 1998). There were only 2 statements from the sample categorised as QQ (Quantitative), one of them was for a statement about the heated flasks, as can be seen in table 8 where we present the categorisation for the questions *Explain spectrum* and *Compare heated flasks*.

Table 8. Comparison of the number of students categorised in the qualitative/quantitative categories for two of the questions, spectrum and compare flasks.

	Phenomena	QEv Everyday language	QSc Scientific language	QHq Half quantitative	QQ Quantitative
Group 1:1*	*Explain spectrum*	**5**	**7**	**1**	**-**
	Compare heated flasks	**11**	**3**	**-**	**1**
Group 3	*Explain spectrum*	4	11	5	-
	Compare heated flasks	11	8	3	-
Group 1:5*	*Explain spectrum*	**2**	**9**	**2**	**-**
	Compare heated flasks	**6**	**4**	**4**	**-**
Group 5	*Explain spectrum*	3	1	3	-
	Compare heated flasks	6	5	1	-
Group 7	*Explain spectrum*	5	11	5	-

	Compare heated flasks	17	9	-	-
Group 1:8*	*Explain spectrum*	**-**	**2**	**4**	**-**
	Compare heated flasks	**-**	**4**	**3**	**-**

* Longitudinal data

There is no obvious progression between the student groups in the cross-sectional data for this aspect either, but the group 3 stands out here too, as it did concerning description matter.

However, the longitudinal data has an obvious trend towards more scientific and quantitative explanations. Also we can see that the scientifically more advanced phenomenon in table 8, the spectrum, entices the students to be less scientific. They are using constituents from less abstract models in their explanations compared to them for the flasks, see table 8. Again we see evidence of students reverting to less sophisticated explanations when faced with complex and difficult phenomena.

Conclusion and Implications

Our results from the cross-sectional sample indicate that students are influenced by the context in their use of explanatory models. They change the constituents of their explanations for the different phenomena. Few students used a particle model of matter in all their explanations. The students showed a context dependence of their explanations connected to the phrasing of the questions. Questions involving drawing a picture makes the students draw more frequently on a particle model of matter. This means that the students do know about the particle model, but choose not to draw upon it for some of their explanations, frequently the first ones. They seem initially to prefer a less abstract explanation.

A physicist or a physics teacher normally draws on a more abstract explanatory model when explaining a more abstract phenomenon. However, the students in this work show a tendency towards the opposite and tend to draw on less abstract models for the complicated phenomena of the flames. The students initially use a less abstract and maybe more familiar explanatory model for the advanced phenomena. This is in accordance with the results of Treagust et al. (2002).

Through the longitudinal design we were able to analyse the development of the individual students' responses through the years of their education. It gave us information about the students that the cross-sectional data did not. It was easier to trace the impact of the different courses on the student explanations, and a progression in use of scientific concepts and model constituents were seen. The fact that we followed individual students seems to make a profound difference. We can learn more about the student explanations and what lies behind them, even though we do not have detailed data on what has influenced the students during the years at university. In a special issue on longitudinal studies White and Arzi (2005) states that a longitudinal study simply allows a more detailed description of the factors that affect learning. Furthermore, they say that differences between groups in a cross-sectional study are assumed to be due only to the experiences the students have had during the elapsed time. However, the groups are not always comparable, as we have seen here. Only in the longitudinal data could we see traces of the inevitable progression of model use in the students' explanations. Our conclusion concurs with White and Arzi (2005) in that if we wish to understand important changes during a 4½ year science teacher education we have to stretch our research over that same time.

Another aspect is the comparison between written surveys and interviews. Through the interviews it is possible to obtain further details of the student explanations, and their use of different explanatory models. This is true even though we used written questionnaires in two steps to simulate the interview situation. Also the importance of the experiments in the interviews is stressed by the students, who say it is easier to predict and discuss when the phenomena are presented in a “real” situation.

A direct implication for teaching and for future research of this study is the importance of discussing the nature of models, compare different models, and to discuss phenomena where one explanatory model does not suffice. One of the intreviewees changed his explanation when confronted with the fact that the balloons behave the same. He explained tha actual behaviour by using a particle model, which he also used for other contexts. He needed to try to use his own model, namely thinking based on “hot air rises”, in a prediction and find that it did not suffice, before he could start using a particle based model in his reasoning.

Also phenomena where scientific facts have different degrees of certainty should be used (Elby and Hammer, 2001). In this way teacher and students are able to address both the distinctions between, the limitations and applicability of the theoretical models.

Bibliography

Cobern, W. W. and Aikenhead, G. S. (1998), Cultural Aspects of Learning Science. I H,J. Fraser och K.G. Tobin (Red.), *The International Handbook of Science Education*, 1998 Kluwer Academic Publishers.

Coll, K. R., France, B. & Taylor, I. (2005). The role of models/and analogies in science education: implications for research. *International Journal of Science Education* 27, 183-198.

Craven, J. A., Hand, B. and Prain, V. (2002). Assessing explicit and tacit conceptions of the nature of science among preservice elementary teachers. *International Journal of Science Education* 24, 785 – 802.

Crawford, B. A. and Cullin, M. J. (2004). Supporting prospective teachers’ conceptions of modelling in science. *International Journal of Science Education* 26, 1379 – 1401.

Driver, R., Leach, J. T., Millar, R. and Scott, P. (1996) *Young People's Images of Science*. Open University Press. ISBN 0-335-19381-1.

Elby, A. and Hammer, D. (2001). On the substance of a sophisticated epistemology, *Science Education* 85, 554-567.

Engel Clough, E. and Driver R. (1986). A study of consistency in the use of students' conceptual frameworks across different task contexts, *Science Education* 70, 473-496.

Eskilsson, O. (2001) En longitudinell studie av 10 – 12 åringars förståelse av materiens förändringar [A Longitudinal Study on 10-12-Year-Olds´ Conceptions of The Transformations of Matter], Göteborg. *Studies in Educational Science* 167, Acta Universitatis Gothoburgensis.

Galili, I.; Hazan, A. (2000). Learners' knowledge in optics: interpretation, structure and analysis. *International Journal of Science Education* 22, 57-88.

Giere, R. N. (1997). *Understanding Scientific Reasoning* 4:th Edition. Orlando: Harcourt Brace College Publishers.

Justi, R. S. and Gilbert, J. K. (2002). Modelling, teachers’ views on the nature of modelling, and implications for the education of modellers. *International Journal of Science Education* 24, 369-387.

Justi, R. and van Driel, J. (2005). The development of science teachers’ knowledge on models and modelling: promoting, characterizing, and understanding the process. *International Journal of Science Education* 27, 549-573.

Petri, J. and Niedderer, H. (1998). A learning pathway in high-school level quantum atomic physics. *International Journal of Science Education* 20, 1075-1088.

Redfors, A. and Niedderer, H. (2004). Cognitive Developement in a Learning Process about Electric Circuits. In E.K. Henriksen och M. Ødegaard (eds). *Naturfagenes didaktikk – en disiplin i forandring? Det 7. nordiske forskersymposiet om undervisning i naturfag i skolen*, s 399 – 413, Kristiansand: Høyskoleforlaget.

Redfors, A. and Ryder, J. (2001). University physics students' use of models in explanations of phenomena involving interaction between metals and radiation. *International Journal of Science Education* 23, 1283-1301.

Ryder, J. and Leach, J. (1999). University science students' experiences of investigative project work and their images of science. *International Journal of Science Education* 21, 945-956.

Ryder, J. and Leach, J. (2000). Interpreting experimental data: the views of upper secondary school and university science students. *International Journal of Science Education* 22, 1069-1084.

Songer, N. B. and Linn, M. C. (1991). How do students' views of science influence knowledge integration? *Journal of Research in Science Teaching* 28, 761-784.

Taber, K. S. (2000). Multiple frameworks? Evidence of manifold conceptions in individual cognitive structure. *International Journal of Science Education* 22, 399-417.

Tiberghien, A. and Megalakaki, O. (1995). Characterization of a modelling activity for a first qualitative approach to the concept of energy. *European Journal of Psychology of Education* 10, 369-383.

Treagust, D. F., Chittleborough, G. and Thapelo, L. M. (2002). Students' understanding of the role of scientific models in learning science. *International Journal of Science Education* 24, 357 - 368.

Tytler, R. (1998). The nature of students' informal science conceptions. *International Journal of Science Education* 20, 901 - 927.

White, R. T. and Arzi, H. J (2005). Longitudinal Studies: Design, Validity, Practicality, and Value. *Research in Science Education* 35, 137 – 149.

Appendix A. The questionnaire.

The first questionnaire

The Flames I

1. The burner is burning with a bluish flame, while the flame of a candle is yellowish. What is happening within the flames? Explain your thinking in detail about:

1a. why it feels warm?

1b. why it shines?

1c. why the flames look different?

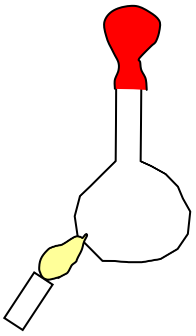
2. Imagine a pair of super magnifying glasses that makes you see all the small constituents of the flames. Draw a detailed picture of the magnified image that you see of the flames, name all parts.

3. Sometimes it is possible to explain in more than one way. Can you imagine another way to explain what is happening within the flames, than the way you chose above? Explain your thinking in detail.

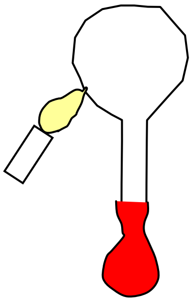
4. The flames are visible and we can feel them if we are close. Does this mean that the flame ”exists”? Explain your thinking in detail.

The Flask I

1. Each of the diagrams below shows a flask with a balloon slipped over the neck of the flask. In each case the balloon is deflated. Imagine that you heat each flask according to the diagrams.



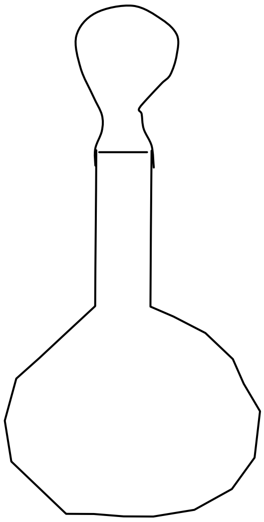
1. Vertical, up

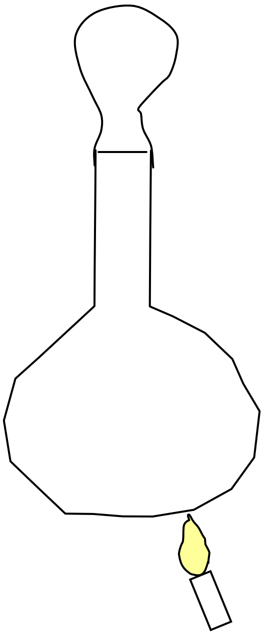


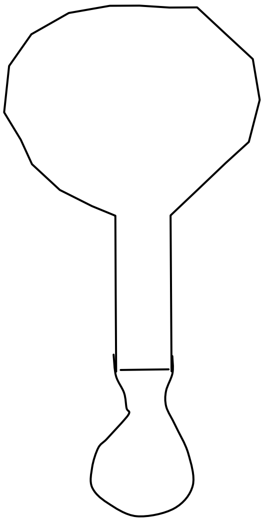
2. Vertical, upside down

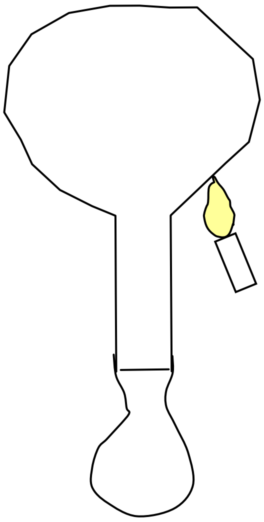
Write, in as much detail as you can, how you think the heating will affect the balloon in the two cases. Make comparisons and explain your thinking in detail.

2. Imagine a pair of super magnifying glasses that makes you see all the small constituents of air in the flasks. Draw a detailed picture of the magnified image that you see of the contents, before and after the heating, name all parts.









3. Sometimes it is possible to explain in more than one way. Can you imagine another way to explain what is happening within the flasks, than the way you chose above? Explain your thinking in detail.

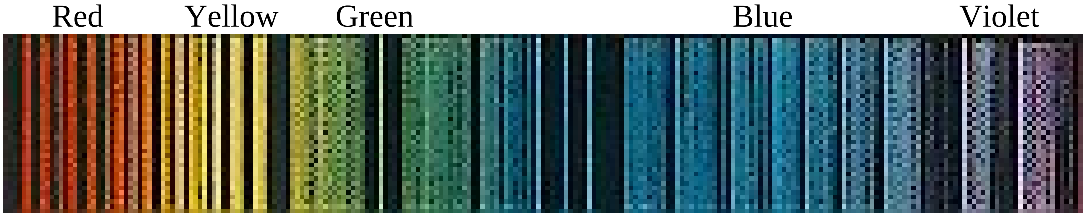
4. The air in the flask is invisible, but we “know” that it is there. Does this mean that the air ”exists”? Explain your thinking in detail.

The second questionnaire

The Flames II

1. So the burner is burning with a bluish flame, and the candle flame is yellowish. Describe what is happening within the flames by discussing the behaviour of very small particles. Make comparisons and explain your thinking in detail.

2. If the light from the blue flame passes a spectrometer we can see a spectrum with many very thin coloured lines, see the figure below.



Explain in detail what the processes in the flame are that cause these thin lines.

3. With your super magnifying glasses you can see these processes in detail. Draw a detailed picture of what you see.

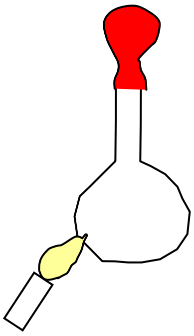
4. Five students are expressing their view of the flame and of their explanations. Mark with an X in the appropriate square whether you agree or disagree with their statements.

Statements from students	**Agree** **Not at all ... Totally**
Christina: *Of course the flame exists. I see it and it is real.*	1 2 3 4 5
Kristian: *A theory of the flame describes how it really is in the flame.*	
Inga: *No one knows how it is in the flame, not even a physicist. They construct better and better theories, but they remain only theories.*	
Anton: *There is only one correct explanation for the flame. If there were two theories, both could impossibly be true.*	
Siv: *The flame does not really exist. It is just something we see, a construction of the mind.*	
Sven:* *An explanation can never be true. Different explanations are fruitful in different contexts. Therefore there can be two or more explanations that are equally "true".*	

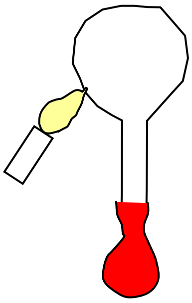
* Added for the last interview with the longitudinal sample

The Flask II

1. Describe what is happening within the flasks and how that influences the balloon by discussing the behaviour of very small particles. Make comparisons and explain your thinking in detail.



1. Vertical, up



2. Vertical, upside down

2. With your super magnifying glasses you can clearly see the constituents of the air in the bottle. Draw the super magnified image that you see of the air particles, i.e. a detailed picture of a particle. Include how the particles are affected by the heating? Draw a detailed picture.

3. Five students are expressing their view of the air in the flask and of their explanations. Mark with an X in the appropriate square whether you agree or disagree with their statements.

Statements from students	**Agree**				
	Not at all		**...**		**Totally**
Christina: *Of course the air exists. I do not see it, but it is real.*	1	2	3	4	5
Kristian: *A theory of the air in the flask describes how it really is in the flask.*					
Inga: *No one knows how it is in the flask, not even a physicist. They construct better and better theories, but they remain only theories.*					
Anton: *There is only one correct explanation for the flask. If there were two theories, both could impossibly be true.*					
Siv: *The air does not really exist. It is just something we see, a construction of the mind.*					