Learning in Science and Mathematics

The LISMA group

On the use of Cognitive Layers in describing a Learning Process about Electric Circuits

Andreas Redfors
and
Hans Niedderer, University of Bremen, Germany

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Department of Mathematics and Science
Kristianstad University, SE-291 88 Kristianstad, Sweden
Phone: 044 - 20 34 Fax: 044 - 20 34 03
e-mail: Andreas.Redfors@mna.hkr.se
http://www.mna.hkr.se/lisma/

Abstract

Learning processes of three college students (prospective elementary school teachers) in the content area of electric circuits have been investigated in a tutorial study. Empirical evidence of cognitive development is coming from an interpretive analysis of transcripts of six tutorial sessions, in which the students use hands-on experiments and special computer software. Data from 1991 are re-analysed with respect to a new theoretical model of cognitive development using cognitive layers, both during the learning process and at its end. We believe that the empirical data can be explained by assuming that the state of the learner's cognitive system at any given time is an association of co-existing models, i.e. that there are different layers of the cognitive system. A cognitive system is a model of a student's mind constructed by the researcher.

1. Background, Aims and Framework

Learning in this paper is analysed in terms of stable elements of a cognitive system, where a cognitive system is a model of a student's mind constructed by the researcher. According to a generalised model of Niedderer and Schecker (1992, p. 84) a cognitive system consists of stable *deep structure* and topical *current constructions*. The subunits of the deep structure are called *cognitive elements*. There are cognitive elements of different kinds described in Niedderer and Schecker (1992). In this paper we are concentrating on conceptions or mental models, i.e. one kind of stable cognitive elements.

Other authors have discussed the possibility of students holding several models simultaneously, and that they use more than one in a single context, e.g Kärrqvist (1985, chapter 10), Marton (1998), Petri and Niedderer (1998), Tytler (1998), Taber (1998) and Eskilsson (2001, chapter 18). It is said that certain elements in a discussion prompt students to use more than one model in a given context during interview situations. In this work we denote the manifold models "*cognitive layers*", see Petri and Niedderer (1998). Taber (2000), who said "*… an individual learner can simultaneously hold in cognitive structure several alternative stable and coherent explanatory schemes that are applied to the same concept area*", uses the term "*multiple frameworks*". Galili and Hazan (2000) express the manifold models as schemes of knowledge with facets. Students' use of manifold conceptions can be further described by introducing the terms *strength* and *status* (Petri & Niedderer, 1998). If an explanatory model is strong, it will be first used in many (new) contexts. Thus, it has a high strength. It also has a special status, in the sense of Hewson (1981), which is defined by the scientific value students attach to the model. Hence, the final state of a cognitive system is an association of different models with varying strength and status (Petri & Niedderer 1998).

2. Methodology and sample

Three college students were selected randomly from some volunteers, enrolled in a physics class for prospective elementary school teachers in San Diego, 1991 (Niedderer & Goldberg 1992). The instruction took place in a special room with video and computer equipment, and it was a clinical study, with the researcher also being the instructor. Each of the six 90 minute sessions over 3 weeks was videotaped with two cameras. One directed at the students, and the other directed either at the computer screen or at the experimental apparatus. The study had some aspects of a natural setting, since the instruction occurred during the same time as a regular class. The same sequence of experiments, nearly the same topics, and the same tests were used.

From a methodological point of view, it was a learning process study with single students in a group, with aspects of both a natural and clinical setting, lasting about nine hours, over a period of three weeks.

The instructional process was guided by the following major ideas.

- Use of open-ended hands-on experiments with batteries and bulbs.

- Use of an electron gas pressure model to describe the electric circuits.
- Use of computer software, which provided a tool for representing students' own ideas about the varying pressure in the circuits.
- Use of student-oriented teaching, with a first phase related to the elicitation of students' own ideas.

The electron gas pressure model assumes electrons in a wire behave like a gas, and that pressure and pressure difference become equated to potential and voltage. The central statement of this model is: the higher the (electron gas) pressure difference between the ends of an electrical device, the faster the electrons will move and the greater the current. A battery is assumed to provide a constant pressure difference across its terminals. The computer-video software represents the electron gas pressure in a wire in terms of the *thickness* of the line appearing on the screen. The aim of instruction was to arrive at a type of scientific thinking based on a relation between agent (voltage V), resistance (resistance R) and a result (current I), OHM´s p-prim (diSessa 1990, p.12).

3. Results

In this paper we report on a renewed analysis of the above described data from 1991. This analysis is focusing on the cognitive development based on two main ideas:

- that stable cognitive elements, i.e. conceptions or models, with varying strength and status, can be used to describe the cognitive development of the learning processes in this case study
- that students in a given context may well use more than one of several, simultaneously held, alternative models during a discussion.

We have analysed discussions and written materials produced by the student based on the two ideas above. Different situations during the teaching process, and artefacts used by the students, e.g. experimental equipment and computer software, have not been taken into account. We have not correlated our results with different aspects of the instructional process.

Transcripts of videotapes were produced for all six sessions. The analysis, based on the assumption of cognitive layers, was done with a qualitative interpretive approach. A qualitative database was established with the computer program NUDIST to promote the iterative interpretation process.

In order to examine the details of the models drawn upon by students we conducted an ideographic analysis. Transcripts were examined with a commitment to reflecting each student’s position as spoken, rather than evaluating a particular response in terms of a set of normative positions. We began the analysis by going through the transcripts looking for statements that to us indicated specific models used by the three students in both their discussions and written assignments. We looked for stable cognitive elements (Niedderer & Schecker 1992), hence a repeated use by a student was required for us to establish a new model. The basis for the categorisation is the analysis of statements in the discussions between students and between students and teacher. We have picked out key words and phrases in student statements and categorized them as indicating specific models, see examples below.

Earlier research has shown that students tend to focus on current as the central concept in the area of electric circuits (Kärrqvist 1985; Duit, Jung, v. Rhöneck 1985; Shipstone et al. 1988; Heller 1990; Voss 1991; McDermott 1991). Voltage and resistance are often seen as aspects or properties of current. Therefore, the focus of this study is mental models associated with current, and we have looked for indications of current models in both discussions and written material.

The rather large number of different models found first were modified and grouped together in an iterative process, ultimately forming five mutually exclusive models. They are mutually exclusive in the sense that no statement has been coded at more than one model. The models represent different ways of thinking about current in an electric circuit. Some of them are well known as prior and intermediate conceptions, while others are intended conceptions of the teaching. Intermediate conceptions are fragmented models generated by the student as a consequence of the teaching, but not intended by the teacher (Niedderer & Goldberg 1995). The five models conform to models presented in previous research (Kärrqvist 1985; Duit, Jung, v. Rhöneck 1985; Shipstone et al. 1988; Heller 1990; Voss 1991; McDermott 1991). The models are described below, elucidated by quotes from the transcripts, and with an increase in scientific status for the last three in the list. Also, well established models from the literature, that we see as included in the respective models, are with each model description. The scientific status for the first two is difficult to establish, since they can both be seen as prior conceptions.

Current as substance

Current is seen as a substance containing energy, like fuel. The idea of substance also represents a possibility to "make choices", e.g. take shorter paths, share and so on.

"So, it's just gonna come here and find that it's got another path to take, and gonna take that path." (Student C, session 6)

Includes: Sink model, sequential reasoning, local reasoning, steady current source, sharing current, no room to go, choosing shorter path.

Positive and negative currents

Two different kinds of current, i.e. positive and negative, are required to light a bulb.

"Because this one's probably from the positive side and this one's coming from the negative?" (Student G, session 4)

Includes: Clashing currents. closed circuit.

Electron current

Particles moving in the circuit constitute the current. The concept electron is often mentioned.

"Cause...cause the movement of the electrons is...is being...impeded by the..."

(Student C, session 4)

Includes: Moving electrons, sequential reasoning, local reasoning, steady current source

Current with electron gas pressure

High electron gas pressure gives a current, and high and low pressure are used in predictions and observations of circuit behaviour.

"Right. And then it's...At this point right here it's the lowest. And at this point it's the highest. But in between, it's going...It just going down." (Student C, session 2)

Includes: Steady current source, electrons circulating.

Current given by electron gas pressure difference

Electron gas pressure difference gives the speed of the electrons, i.e. the current, and circuit reasoning is sometimes indicated.

"It won't be...It still won't be as bright as this, cause there's not as much a pressure difference between the two things. Actually..." (Student C, session 5)

Includes: Circuit reasoning, Ohm's model, circulation.

3.1 Examples of layers

Our qualitative analysis of the transcripts has found several examples of students using words and phrases that indicates use of different models in a given context, also during short time intervals. We illustrate this with four examples, each focusing on a specific student.

Example 1. Circuit with a gap, student C (Session 2).

Circuit under discussion is shown in figure 1.

C: Well, it wouldn't light. The li...It wouldn't light!

H: It wouldn't light?

C: No. Because the **electrons would have nowhere to go** and and they **wouldn't have to move**. So...wouldn't light.

H: Perhaps you should explain why it wouldn't light.

C: Because the electrons are moving down and going to there. It **needs the positive and the negative**, um, charges. I mean...charges? Are we talking about charges, here?

G: Um-hum.

H: Yes. That's okay.

C: Okay. It **needs positive and negative charges** in order to light. Because they have to... you know, go to each other and...that's how they move up there. If they have...the negative ones are goin' up there and makin' it move. And if there's nowhere to them to move to, then **they're just gonna stay there and not do anything**.

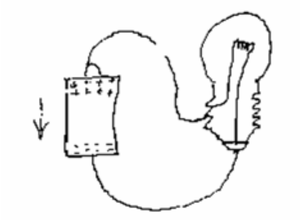

Figure1. Circuit example 1.

This is an example where the expressions "electrons would have nowhere to go", "wouldn't have to move" and "they're just gonna stay there and not do anything" implies use of the model *Electron current*. The expression "needs the positive and the negative" implies model *Positive and negative*. The implication is that student C is using both these different models in the discussion.

Example 2. Two bulbs in series, student L (Session 2)

L: It's sharing the current.

H: Would you explain? What do you mean by sharing the current?

G: Because **it has to go** in through...It goes in here, okay? This **high pressure goes through here**. And then it uses a bunch of it at the bulb. We already decided that. And, so when it's coming through here, it's still kinda lagging, it's kinda lagging. And then it **hasta go through and he hasta use more pressure**. An we don't have as much pressure to give as we did over here. So it has to share.

C: Well, then why wouldn't one be lighter than...one be brighter than the other one? You know what I mean? It would seem...I mean...I, I agree with what you say.

L: I think...that...if...(inaudible) is, you know, we discov...I hooked it up just to that other wire, we would discover that this would.. .would be a right light. But since this is **taking...pressure and electrons** away from this...it's gonna dim this light. And then here they **hasta go** again and then the **electrons'll be pulled away** again. So each time...

H: What is taken away?

L: The **pressure of the electrons**.

H So sharing the current. What does that mean?

C: Well, the current is now having to light two bulbs, instead of just one. So the two bulbs are sharing the current that's coming from the thing.

H: So one uses one half and the other uses the other half?

G: Not actually that much – but...half of what it was supposed... what it used before.

L: I think what happens is that...This would be fine, but as soon as it gets to here, it's getting drained, cause it doesn't have enough...to light this. So it's actually pulling from...It's **pulling electrons**...pulling...Yeah. It's pulling electrons from here. So there's not as much **movement** inside here which makes it a less light...because this one **needs it**. It's not so much...maybe that they **share**...it's just that...Like, when it leaves here, if we just...you know, ended it. It would seem like it was fine. But as soon as **it hits this point** and realizes that it **hasta**...have enough pressure to...light another bulb, it kinda drains from this one. Now it's doing nothing. Oh, it is, huh?

Explanations with "sharing the current", "hasta go", "drains from" implies model *Current as substance*. Explanations containing "electrons'll be pulled away", "pulling electrons", "movement" implies model *Electron current*. The expression pressure of the electrons implies model *Current with electron gas pressure*. Thus, the implication is that student L is using three different models during this discussion, prompted by peers and teacher.

Example 3. Three bulbs, student G (Session 5)

Circuit is shown in figure 2. First prediction by the students was that bulbs A and B would light, but not C. The arguments were based on model *Current as substance*, i.e. shorter path. The discussion continues:

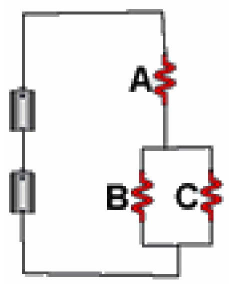

Figure 2. Circuit with three bulbs and two batteries.

G: Unless it gonna...unless the **faster path** they choose is just this, and then these two (A and C) will light. And this one wouldn't.

H: So. Tell me again.

G: We think that it's either gonna...No wait! But the resistance are all the same, though.

C: Yeah, that's right...

G: So I think all of them will light.

>>>

G: But then, since they all have the same exact resistance, like before, remember? And they all kinda spread out. Remember with the one and the one behind it. They all lit.

>>>

H: Okay. Then I ask you the next question before doing it. Will they all be light the same brightness?

G: I think they will.

>>>

G: They're **gonna be half and then they'd come together** and make one again.

L: I don't know. No, wait! If this is **sharing**...

G: There's **double coming out**. I mean, or

L: It's splitting and it's gonna be either one by...one time...or each one, remember how we were doing that...Tuesday? If this is like 2X, then these will be 1X, but if they come back together, it'll be...

G: They're gonna be half and then they'd **come together** and make one again.

L: So you don't think they're all the same?

G: I think they're all the same.

H: All be the same?

G: You can just write something else.

L: I don't think...I just don't think...I don't think they'll be the same.

H: Well, perhaps you can really decide your prediction yourself. I prepared a sheet of paper on that. I wrote some letters so you can make a precise prediction.

G: **Pred:** I feel that A B & C will light and they will all be of equal brightness.

Obs: B & C were dimmer than A. But they all lite. There is more of a **pressure difference** in A than in B and C. Because they have to **share**. all the current is the same except when it is **split up** to go to B & C.

Expl: Currents are same throughout but then if it comes to a fork it separates evenly: then reunites. **Pressure difference**: **bigger** pd=**brighter** light; vice versa. There is **more** of a pd in A. Because there is **more** current. Because B & C were **sharing**. So that is why A is brighter than B C. Resistance: where the resistance is the same pd's current are the same. The resistance is same of B & C that is why they were equally lite.

Explanations with "faster path", "They're gonna be half", "they'd come together", "share" implies model *Current as substance*. The expressions "double coming out", "pressure difference" implies model *Current with electron gas pressure*. Thus, the implication is that student G is using two different models in the discussion. Notice, that the prediction, observation and explanation are statements the student was required to write down before, during and after the experiment. This represents a different kind of data compared to the transcribed discussion preceding it. In this kind of data the model *Current with electron gas pressure*, a model with higher status, is more frequent.

Example 4. Three bulbs, student C (Session 6)

Circuit under discussion is shown in figure 3.

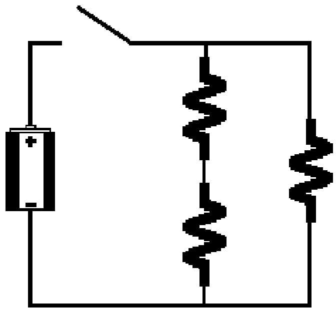

Figure 3. Circuit example 4.

L: Oh, so, so, closing it will mean that it closes up the circuit, which means that –

H: Yes.

L: Current will go through it? Okay.

H: Yes. But, think about the three bulbs, please.

C: Okay, this is, **this is negative**.

L: High.

C: **High**, going, see but the thing is –

L: Split.

G: Oh, no. There're two different wires! There're two different wires.

L: There's a wire goin in here. There's a wire goin out here. A wire goin in, and a wire. And then there's one that connects these two, also.

H: Yes. Yes.

L: So, let's see. It's gonna come –

G: So, it'd be easier for it to go like this.

L: Go the straight way between this.

G: So, because it'll be easier for it to come through this, and then go up here -

L: And go straight.

G: And then, no! Go back this way, cause, to go inta the bulb, it's more resistance, it's just gonna go up this way.

L: There's more resistance, than there is in the wire.

C: So, it's just gonna, like, **meet**, it's just **gonna meet** over here. And then just **go around**. And these two aren't gonna light.

H: ... would not get light.

C: Right.

L: These two. Is that wh, ...is that what you said?

C: If it's gonna, yeah. Because I think this **path is shorter**. It doesn't have as much –

G: Resistance.

C: (In unison with) Resistance. It's **less resistance going around that way** –

H: That's an interesting statement. Yes.

C: So, it's just **gonna come here** and find that it's got **another path to take**, and gonna take that path.

H: Yes.

C: And then just, light that.

H: But, think about pressure difference. What do you think about pressure difference?

C: Well, **it's high**

Student C starts the discussion with statements like "this is negative" and "high" implying model *Current with electron gas pressure*. Then continues the discussion, prompted by here peers, using words like "meet", "gonna meet", "go around" and "path is shorter", implying model *Current as substance*. Starts an explanation using "less resistance going around that way", but when clarifying uses a statement: "gonna come here and find that it's got another path to take". Again, this implies *Current as substance*. Student C finishes the discussion with the statement "it's high" indicating use of model *Current with electron gas pressure*. The implication is that student C is using two models in this discussion, starting and ending with *Current with electron gas pressure,* but using *Current as substance* in between. Students L and G are giving the incentive to revert back to *Current as substance* with their comments, and the teacher H prompts the use of *Current with electron gas pressure* (higher status). After the last quote in example 4, the discussion continues with statements indicating use of models with electron gas pressure.

In this case student C falls in with her peers in using a model of high strength. *Current as substance* has a high strength for all three students, even in the last session (session 6). The teacher on the other hand uses model *Current given by electron gas pressure difference* in a question, and this prompts her to use a more sophisticated model, a model of higher status, i.e. *Current with electron gas pressure*. Notice, that the short statement "it's high" is coded at *Current with electron gas pressure,* a less sophisticated model than the one used by the teacher. The statement does not indicate the most advanced model.

3.2 Development over time

Previous papers, e.g. Niedderer and Goldberg (1995), have reported on empirical evidence for a description of students' learning pathways from a prior conception "everyday current" to three new intermediate conceptions "positive and negative current", "microscopic view of current", and "current with electron pressure". However, in this work we do not see the pathway as a classical "path", but rather as a quantum mechanical "path" where initial, intermediate and final "states" are represented by a combination of several different models. A view similar to that expressed by Bao and Redish (2001) in a paper on quantitative analyses of large population student responses.

The learning process of a student would be characterized by several coexisting models interchanging to be the most frequently used. The models used by the students during the six sessions of the teaching sequence are shown in figure 4. The diagrams show use of several coexisting models, and are similar for the three students.

The model *Positive and negative* is frequently used in the first session. It was introduced by L and picked up by the two other students. The influence from the peers could be noticed very clearly. The students' models evolve as a consequence of the ongoing discussion in the group. However, it is the input from the teacher that drives the process towards models of higher scientific sophistication, i.e. models with higher status. For student L, model *Positive and negative* recedes with time, when other models become used more.

In the sixth session student L is using the most advanced model, *Current given by*

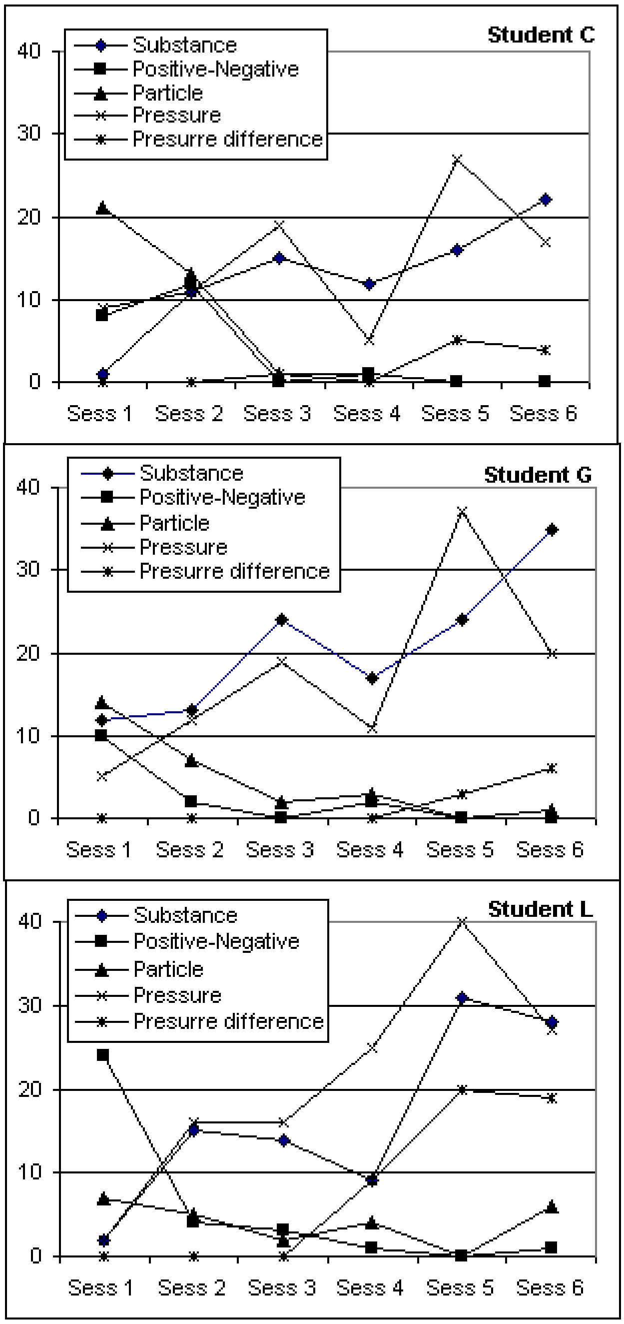

Figure 4. Models used by students during the six sessions.

pressure difference, several times. The data shows that almost all models are used by the students in the sessions, also towards the end of the teaching sequence, thus indicating the existence of layers in the cognitive system throughout the sequence. This is in accordance with (Petri & Niedderer 1998). Notice that use of several models is indicated even within discussions of one given phenomenon.

3.3 Strength and status

In a given instant students will use one single model, but their use of models change rapidly and more than one can be used during short discussions. We propose that the model first used and the pattern by which the use of models changes depends on the strength and status of the models. A high strength means that the model will be used first. It comes strongly in new situations. The status is simply a measure of the status attributed to the model by the student. Status is based on the level of scientific sophistication ascribed to the model by the student. The assumption is that students often will switch to models of higher status if their reasoning is questioned or debated by a teacher, and sometimes also when questioned by peers.

The model *Positive and negative* is strong in the first session for student L, but recedes as other models grow stronger, see figure 4. The frequent use of model *Current given by pressure difference* in the sixth session by student L indicates that it has become a model with high strength. We propose that the data indicates that strength and status of the models are decisive for the use of models during the discussions. We give two examples to illustrate our reasoning; one from session 2, and one from session 5.

The quotes in example 5 are from session 2 where the interplay between strength and status is indicated.

Example 5. Two bulbs in series, student L (Session 2)

The quote is taken from a later part of session 2 compared to example 2.

L: I think what happens is that...This would be fine, but as soon as it gets to here, it's getting drained, cause it doesn't have enough...to light this. So it's actually pulling from...It's pulling electrons...pulling...Yeah. It's pulling electrons from here. So there's not as much movement inside here which makes it a less light...because this one needs it. It's not so much...maybe that they share...it's just that...Like, when it leaves here, if we just...you know, ended it. It would seem like it was fine. But as soon as it hits this point and realizes that it hasta...have enough pressure to...light another bulb, it kinda drains from this one. Now it's doing nothing. Oh, it is, huh?

>>>

L: I was tryin' to light this over here, but I didn't get it right. It should be, what? A little bit farther out here, and then start coming down twist it into the bulb. So, let's see. There's gonna be...a decreasing pressure here. An all of a sudden it's gonna get to that bulb.

Um-hum.

L: And it's gonna take -

C: lots more.

L: even more , so it's gonna...just keep...decreasing, I guess.

L: And then we'll...what...I...I know what I think, it's...hard to draw.

H: It's hard to.

G: How do you explain?

L: But does that make sense, though? That, like...it's got this current. It's going just fine. Okay, this high pressure's coming out here. And it's going in here and it lights this {the first bulb} up just fine. And it goes and goes and goes and oops! Golly! We have to have enough power. Here we are lowering down. We're going. We're going.

L: Thinking we're going to get back to the battery. But no, now we have to light another bulb. So , it just kinda goes, "Oh, I need some help!" "Give me some of those electrons back." Or whatever. So then it kinda...takes away from...takes electrons from this to try to light this one.

>>> (Teacher intervenes and talks about electron gas pressure)

L: So the drop in pressure increases current, right?

H: Pardon?

L: A...a...change in pressure...a pressure difference...increases current?

The first statements of student L are coded as *Current as substance*, indicating that this model has a high strength. It is used first as the discussion starts. Student L ends this conversation by two statements indicating the use of model *Current with electron gas pressure*, or even model *Current given by electron gas pressure difference*. This is after the teacher has talked about the electron gas pressure model. Our conclusion is that the teacher's intervention prompts the use of a model with higher status. Student L uses models with electron gas pressure more often after this occasion. The strength of these models increase during the following sessions, se figure 4.

Example 6. Strength and status, student L (Session 5)

Discussion about the same circuit as in example 3, see figure 2, but in this case a short circuit of the bulb B is introduced.

L: Then it's gonna go this way. It's gonna go this way, (whistle), it's gonna go straight through here. It's not even gonna touch this thing. It's gonna all be...

>>> *(Student C starts writing on her paper and starts to use Current with electron pressure)*

C: Well, it'll split up. One will go this way and one will go that way. So double high...will go over here? And double high will take the shortest path which is...right there?

L: Double high? What do you mean?

C: Yeah. Double high comes out here.

G: Yeah.

L: You can't have double high gonin' both ways!

C: Yeah. You can.

>>> *(Discussion goes on, but L is not convinced)*

L: Wait a minute! I think we better think this through again. Real quick.

H: It's very nice, yes? I think this was a step towards the truth, but it was not the truth.

L: *(While she writes on her worksheet.)* What am I doing here? I've got this extra wire here. So this is gonna be the same, with this 2 high power coming through here. Got 2 pressure over here and 2 pressure here.

C: Wish I didn't write in pen.

L: *(Still at worksheet.)* Then we had high pressure coming outta here, right?

C: Um-hum.

G: But this will still be double pressure coming from here.

C: Um-hum. Oh! So it's gonna be double pressure and this is gonna be...high pressure

G: (In unison with C) Single high pressure.

L: This is gonna be high coming through here and we're still gonna have double. It's not gonna...there isn't gonna be...any pressure difference. It's just gonna go straight through that...wire.

>>> *(Discussion goes on using models of electron gas pressure)*

L: If this is gonna come out 2 high over here. This is gonna come out high cause it...cause of the pressure difference here. This one has no pressure difference cause it's not going through –

In this example we see student L start the discussion with statements indicating use of model *Current as substance*, but when student C starts to use *Current with electron gas pressure*, student L follows. This is a model with higher status for the students, and it is probably coming in use because student C starts to write down a prediction. The model *Current with electron gas pressure* has now, in session 5, also a high strength for student L, who switches over to this model to follow the group. Notice that model *Current with electron gas pressure* continues to be used by student L in example 6. The process of writing further reinforces student L to use an electron gas pressure model.

4. Conclusions and Implications

We believe that the empirical data can be explained by assuming that the state of the learner's cognitive system at any time is an association of co-existing mental models, i.e. that there are different layers of the cognitive system. Furthermore, we believe that there is a superior administration. Different models will be used in explanations depending on the strength and status attributed to them by the learner. Models with high strength will predominantly be used first in a new context, but after external or internal stimuli, models of lesser strength will be used, see Petri and Niedderer (1998). Moreover, the stronger a model is represented, the less it is depending on the special context. We have seen the model *Current as substance*, which is strong with the students, used in all possible contexts during the six sessions.

In several cases it seems appropriate to attribute a status to the models. We have observed indications that models, to which we believe students attribute a high status, are used when the teacher or the peers prompt it by their comments or questions. Models we believe have a higher status are used when students answer specific question from the teacher, and when they are writing on their worksheets. Thus, we have seen indications of a superior administration of models used by the student, and we believe that the individual development of strength and status for the different models can be followed through the data.

Further studies on the use of cognitive layers to describe learning in different content areas of physics would be of interest. This would bring other perspectives on the idea of cognitive layers since different content areas in physics are inherently different in range of available scientific models. One such study was reported by Petri and Niedderer (2001) who used layers of conception to analysis learning processes in the content area of atomic physics.

An implication for real teaching of this work is that introducing students to a model using a set of exemplary circuits will not necessarily lead them to draw on only this model for other circuits, intermediate models are likely to appear. Of course, teaching using exemplary phenomena is an important first step as students begin to understand the key elements of a model. However, we suggest discussions of different models to challenge the students' coexisting models. In this way teacher and students are able to address *strength* and *status* for, distinctions between, and limitations of, the models.

5. Bibliography

Bao, L. and Redish, E. F. (2001). Concentration analysis: A quantitative assessment of student states. *Am. J. Phys. Suppl.*, 69, S45-S53.

Duit, R., Jung, W., v. Rhoeneck, C. (1985) Aspects of Understanding Electricity, IPN-Arbeitsbericht 59, Kiel.

Eskilsson, O. (2001) En longitudinell studie av 10 – 12 åringars förståelse av materiens förändringar, Göteborg. *Studies in Educational Science* 167, Acta Universitatis Gothoburgensis.

Galili, I.; Hazan, A. (2000). Learners' knowledge in optics: interpretation, structure and analysis. *Int. J. Sci. Educ.*, 22, 57-88.

Heller, P. (1992). Variable Uses of Alternative Conceptions - A Case Study in Current Electricity. *Journal of Research in Science Teaching* 29(3), 259-275.

Hewson, P. W. (1981) A conceptual change approach to learning science. *European Journal of Science Education* 3, 383-396.

Kärrqvist, C. (1985) Kunskapsutveckling genom experimentcentrerade dialoger I ellära, Göteborg *Studies in Educational Science* 52, Acta Universitatis Gothoburgensis.

Marton, F. (1998) Towards a Theory of Quality in Higher Education, in: Bart, R., Boulton-Lewis, G. (eds.): *Teaching and Learning in Higher Education* (p.177-200), Hawtorn: ACER, cop.

McDermott, L.C. (1990) Millikan Lecture: What we teach and what is learnt-Closing the gap, American Journal of Physics 59(4), 301-315.

Niedderer, H.; Goldberg, F. (1992): A study of thinking and learning in electric circuits. Paper presented at NARST, Boston, March 21-25, 1992.

Niedderer, H. and Goldberg, F. (1995). Learning pathway and knowledge construction in electric circuits. Paper presented at European Conference on Research in Science Education. University of Leeds.

Niedderer, H., Schecker, H. (1992) Towards an Explicit Description of Cognitive Systems for Research in Learning Physics, in: Duit, R., Goldberg, F., Niedderer, H. (eds.): *Research in Learning Physics - Theoretical Issues and Empirical Studies*, Proceedings of an International Workshop in Bremen, IPN Kiel.

Shipstone, D.M., von Rhoeneck, C., Jung, W., Kärrqvist, C., Dupin, J.J., Joshua, S., Licht, P. (1988) A study of students' understanding of electricity in five European countries, *International Journal of Science Education* 3, 303-316.

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

Petri, J. and Niedderer, H. (2001) Atomic Physics in Upper Secondary School: Layers of Conceptions in Individual Cognitive Structure. To appear in the proceedings of the Third ESERA conference *Science Education Research in the Knowledge based society*, Thessaloniki, Greece.

Taber, K. S. (1998). An Alternative Conceptual Framework from Chemical Education. *International Journal of Science Education* 20, 597-608.

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

Tytler, R. (1998): The nature of students' informal science conceptions. *Int. J. Sci. Educ.*, 20, 901 - 927.

Voss, H.-P. (1991). Fehlvorstellungen und der Gebrauch genereller Schemata in der elementaren Elektrizitaetslehre. In H. Wiesner (Ed.), *Aufsaetze zur Didaktik der Physik II. Festschrift zum 65. Geburtstag von Walter Jung* (pp. 274-290). Bad Salzdetfurth: Franzbecker.