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REASONING ABOUT ELECTROCHEMICAL CELLS IN A CONCEPT MAPPING ACTIVITY AND IN THE SCHOOL LABORATORY

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Abstract. In this paper, we study students' actions in the classroom as a matter of learning to participate in situated practices. We investigate how learning is constituted in two classroom activities commonly regarded as directing students towards manipulating either concrete material or scientific ideas. We audio-recorded pairs of students as they engaged in a common reasoning task about electrochemical cells, either as part of constructing a concept map or working with a real electrochemical cell. In both settings students needed to learn the rules, norms and techniques of the practice as part of their reasoning. This included techniques for attaining an acceptable concept map, or for how to make correct and relevant measures of current and voltage in the electrochemical cell. Students also learned norms for including terms in the concept map, or for distinguishing and naming particulars of the electrochemical cell. Our results show that similarities and differences between two classroom settings can be specified in new ways by studying them as situated practices. How science is taught in the classroom may not primarily be framed as questions about the effectiveness of different methods, but of what students need to learn in order to act competently in different relevant practices.

1 Introduction

There is a large amount of work published showing students' conceptual difficulties in science (Duit, 2007; Kariotoglou, 2002). A general observation from that research is that instruction often fails to engage the ideas that students bring to the classroom, thereby leaving their everyday conceptions intact throughout the school experience (Driver et al., 1994). Accordingly, there is an extensive amount of research trying to find ways of making students go "minds on", as it were, in order to make teaching more effective in attaining the intended conceptual learning (Leach & Scott, 2002; Méheut, 2004; Vosniadou et al., 2001). Labwork and concept mapping are two teaching activities that have attracted much interest from science education researchers as to their effectiveness on students' learning in science (Lunetta et al., 2007; Nesbit & Adesope, 2006).

Concept mapping has emerged as a method with the potential to engage students' ideas head-on (Nicoll, 2001; Åhlberg, 2004). Concept mapping is typically considered to direct students attention towards abstract reasoning about relations between concepts of a science topic (Nesbit & Adesope, 2006; van Boxtel et al., 2000), as well as to help them represent their own cognitive structure (Nicoll, 2001; Slotte & Lonka, 1999). In a meta-analysis of the effects of learning with concept maps, Nesbit and Adesope (2006) found a small positive effect on knowledge retention and transfer, but they were not able to attribute this to concept mapping as such rather than to a lower effect of the comparison treatments. In a study on dyads working with an electricity task, van Boxtel et al. (2000) did not find any effect of concept mapping as opposed to producing a poster on the post-test scores. But they did find that students working with concept maps talked more about relations between electricity concepts whereas students working with the poster assignment talked more about relations between the concepts and concrete phenomena.

On the other hand, a central concern with laboratory work is that it tends to direct students' attention towards handling equipment and following prescribed procedures rather than towards working with ideas (Lunetta et al., 2007). Hodson (1993) viewed this focus on the practical details of labwork, this "noise", as unnecessary barriers to learning. Gunstone (1991) concluded that "students need to spend more time interacting with ideas and less time interacting with apparatus" (page 74). On these grounds, some researchers argue that laboratory work is ill-suited and overrated as a means to promote learning of science (Osborne, 1998). Others suggest that procedural and conceptual knowledge are intertwined (Psillos & Niedderer, 2002) or even that students do not understand the meaning of scientific concepts properly until they have learned to apply them in practical procedures (Jiménez-Aleixandre & Reigosa, 2006).

There is considerable variation in learning outcome in both these teaching practices (Lunetta et al., 2007; Nesbit & Adesope, 2006). In labwork, the variation is attributed to the complexity of most labwork tasks (Millar et al. 2002). Lunetta et al. (2007) concluded that the interaction between procedural knowledge, attitudes toward science, and understanding of science concepts and the nature of science needs to be examined carefully to better understand the potential and realities of laboratory experiences. There is less agreement on how to approach the variation in learning outcome in the case of concept mapping. However, some authors assert that concept mapping is something that has to be learned and mastered (Wandersee, 2000; Åhlberg & Ahoranta, 2004). There is also a discussion about what a good concept map looks like, how to improve the methods of concept mapping, and which criteria should be met for a product to count as a concept map in the first place

(Åhlberg, 2004). So even in this allegedly purely conceptual activity there are apparently better and worse ways to proceed. Nesbit and Adesope (2006) concluded that more carefully designed research is needed to better identify the mediating conditions for effective learning with concept maps, stressing that investigations should examine the processes by which students learn with concept maps.

The purpose of this study is to analyze students' reasoning in electrochemistry in two classroom settings commonly regarded as affording either the manipulation of ideas (concept mapping) or the manipulation of concrete material and equipment (laboratory work). The results presented here are part of a more elaborate manuscript that will be published elsewhere (Hamza & Wickman, unpublished). We approached the question of what constitutes difficulties for students in these two settings as a matter of learning to participate in two situated practices (Lave, 1993). Particularly, we are interested in the extent to which students encounter similar difficulties in these two seemingly different activities.

2 Analytical approach

We described and analyzed students' reasoning through the now well established discursive mechanism of a practical epistemology analysis developed by Wickman and Östman (2002). This approach to analyzing student action in the classroom acknowledges that the meaning of words, sentences, or actions is construed within socially shared practices (Lemke, 1990; Wickman, 2004). Both as teachers and researchers, we do not have direct access to students' thoughts but depend on what they do or say as part of an activity (Wickman, 2004). The approach avoids factoring a classroom activity into separate entities, such as students' conceptual frameworks or various contextual factors, supposed to affect students' actions (Greeno, 1997). Indeed, our analytical approach implies that people's actions are not divided into periods characterized by states (e.g., certain conceptions) interrupted by periods of change (e.g., learning). Instead, people live in a series of situation (Dewey, 1938/1996a, p. 25) in which continuity of experience is constantly established (Wickman, 2006). Because there is always something new in each situation, the process of making situations continuous also amounts to a transformation of experience, thus, to learning (Wickman, 2006). On this account learning the meaning of words and actions, for example in electrochemistry, is done through repeated encounters in the practices where these words or actions are used (Wickman, 2006; Wittgenstein, 1953/1997).

This process of establishing continuity of experience may be likened to a rhythm of construing *relations* between what occurs in an experience and what *stands fast* to the participants in the situation (Wickman, 2006; Wickman & Östman, 2002). In encounters occurring in a situation there will be a need to give meaning to them in relation to the whole experience (Wickman & Östman, 2002). Such a need is termed a *gap*. A gap may be filled immediately with discursive relations, or it may first be stated as a question and subsequently filled. If people fail to fill a noticed gap with relations the discourse stops or takes on a new direction. The gap is then said to linger. This approach amounts to a generous and inclusive operationalization of learning (Hamza & Wickman, 2008). Any gap noticed by the students demonstrates a need to fill the gap with relations to what stands fast. An account of the gaps noticed and the relations established to fill these gaps, according to this operationalization, is an account of what students need to learn to be able to proceed with these activities.

Our operationalized research question is: What gaps are important for students to fill in order to proceed with the two activities of reasoning in electrochemistry by (a) constructing a concept map and (b) constructing a real electrochemical cell?

Our analysis is based on two excerpts, one from the CM-activity and the other from the LW-activity. The two groups analyzed are both from the first session of each activity. When students are referring to the concepts written on the bits of paper this is indicated with quotation marks in the excerpts.

3 Study setting

We conducted the study in a municipal upper secondary school in Stockholm, Sweden. We presented the study to the chemistry teacher early on in the chemistry course so that he was able to include it in the regular curriculum for the course. The teacher chose to incorporate the activities of the study in the last quarter of the course. We also acquired written permission from the students to record their talk during the two activities.

The students were already separated into two "lab groups". For this study, one lab group first went to the chemistry lab to do the labwork activity (LW-activity), while the other group went to a regular classroom for the concept map activity (CM-activity). After 75 minutes, the groups changed activity. In both activities, the students worked in pairs as usual when working in the lab. In the CM-activity we audio recorded their talk and video recorded their production of the concept map. In the LW-activity we audio recorded their talk. The chemistry teacher stayed in the chemistry lab, whereas the first author alternated between the two activities.

The students were given identical instructions to discuss and try to explain (a) how a current can occur in *your* (labwork) or *an* (concept map) electrochemical cell, (b) which chemical reactions occur, and (c) what role the glass filter at the bottom of the U-tube has. In the CM-activity we provided 19 different electrochemistry terms (23 if synonymous verbs and nouns are included) on small bits of paper, an A3-sheet, and post-it notes (for additional terms) together with a schematic representation of an electrochemical cell (Figure 1). In the instructions, the students were told to "reason about how and why an electrochemical cell, as the one in the picture, can produce electric current and make a lamp give light". They were also instructed to use the concepts on the slips of paper (a) to support their reasoning and (b) for building a concept map according to a general example provided at the back of the instruction sheet.

In the LW-activity the students were asked to "construct a working electrochemical cell, that is a simple battery, and try to reason about how and why it can produce electric current". Moreover, the students were given detailed instructions of how to set up the cell in order to drive an electric fan or a light-emitting diode. They were also given instructions (a) to observe what happened in the cell, (b) to measure the voltage, (c) to look closely at the metal strips, and before quitting also (d) to connect the fan or the LED to a "real" battery. Figure 1 also functions to illustrate schematically how the real electrochemical cell was set up.

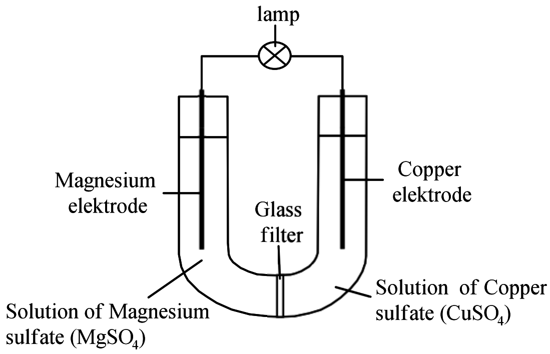

Figure 1. The picture of a schematic electrochemical cell presented to the students in the CM-activity. In the LW-activity, students set up a cell looking like this.

4 Findings

In both settings, reasoning about the electrochemical cell involved learning the rules, norms, and techniques relevant to each practice. At the same time, the specific content of these gaps differed. The students needed to learn rules, norms, and technologies that were specific to each practice. This was contrary to the content of gaps dealing with more conceptual issues where students in both settings identified gaps with similar content. As to the conceptual content, this will only be brought out here to the extent that it forms part of the excerpts showing gaps dealing with the rules, norms, and technologies. The two kinds of gaps, conceptual and, if you will, procedural, often occurred as part of the same line of reasoning. In order to be able to continue reasoning about electrochemical cells, the students needed to establishing relations to fill both kinds of gaps.

4.1 Learning what counts as proper ways to proceed with the activity

In the CM-activity, Andrew and Brian noticed a gap about how to begin their CM:

Andrew	Yeah. Well, so what do we begin with?
Brian	Oh shit [in english] this was hard.
Andrew	Uhm…
Brian	Well there is…
Andrew	Is there like… is there "Electrochemical cells" or something?
Brian	"Electrical energy". How about that? "Chemical energy", "Volt[age]…", "Chemical…"
Andrew	If, but yeah but, that could be something, like this, that something leads to that, they can…
Brian	Shall we make our own then, "Electrochemical cell"?
Andrew	Yeah that's good.

The students fill the gap "what do we begin with?" both by suggesting individual terms (lines 5 – 6) and by establishing relations (that something – leads to – that, lines 8 – 9; we – make our own [term], line 10) expressing rules or norms for how to begin. These students needed to decide on (i.e., learn) these rules in order to proceed with the activity. In the LW-activity, Chris and Daniel similarly needed to learn what counts as a proper start of the activity. Although having set up their electrochemical cell properly, their electrical fan does not move:

12	Chris	Weren't we supposed to make it [the electrical fan] rotate?
13	Daniel	Sorry?
14	Chris	Weren't we supposed to make it rotate?
15	Daniel	Yeah. Let's try to...
16	Chris	But we've got current here alright.
17	Daniel	Yeah.
18	Chris	I think it ought to begin.
19	Daniel	Yeah. You'd think so.

They notice a gap as to *whether* the fan *should* rotate (lines 12, 14, 18 – 19), rather than *why* it doesn't. So they are not entirely sure what to expect and how to act in response to the contingency of a non-working electrical motor in this activity. In the next excerpt Chris and Daniel negotiate what norms to apply to determine whether the fan is affected by being connected to the electrochemical cell:

20	Daniel	Well but we've only got to p… give it a small kick. Does it rotate this
21		much without [the electrochemical cell]? Yes. No, not entirely.
22	Chris	Yes it does.
23	Daniel	Or? Yes. No. No but look, it's going a little here. Oh yeah look, I promise
24		you, it is.
25	Chris	I still think it ought to move slowly by itself as well.
26	Daniel	Yeah maybe. Well, I don't know. Something's wrong with our fan.

Chris establishes the norm that the fan should move without their help (line 25). Daniel, on the other hand, suggests that the norm for having a working fan may be to compare the difference between how easily the fan moves when "giving it a small kick" with and without supply from the electrochemical cell (lines 20 – 24). You might say that it comes down to a discussion about the rules of the game. To close this section, we return to Andrew and Brian in the CM-activity. Here too, they need to agree on the rules of the game:

27	Andrew	We aren't allowed to draw on the paper so it's not that easy to show, but
28		yeah, well.
29	Brian	But I think we should. We're supposed to write there in between.
30	Andrew	But I don't think we're supposed to do that.
31	Brian	Yes I think we are. Let's write there in between. Otherwise we can't really
32		show, what we mean.
33	Andrew	No. Ok, let's do that.

4.2 Learning the techniques of the activity

In this excerpt, Andrew and Brian learn the technique of drawing a reasonable CM (lines 39 – 44, 46 – 52) at the same time as they are reasoning about the conceptual content of the task (lines 36 – 38, 45).:

34	Brian	But "Electrons", where is it [the piece of paper]?
35	Andrew	Here.
36	Brian	Okay. It enters like… It enters in both ["Oxidation" and "Reduction"].
37		
38	Andrew	I mean, electrons are sent away and like…
39	Brian	Uhm, we do like this… Oops, well okay…
40	Andrew	Actually we should put one arrow up, so that you can see it's in that
41		direction.
42	Brian	Yeah. Yes [in english]
43	Andrew	Put it like this, on the arrow, a line so that it…
44	Brian	Like this.
45	Andrew	Or like: "'Electrons', given off, 'oxidation'" [reads]. Strange.
46	Brian	Should we run one all around, "taken up" [draws an arrow from oxidation
47		to reduction around the entire map]
48	Andrew	[Laughs]
49	Brian	It took up a great deal of space.
50	Andrew	[Laughs]. Perhaps a bit too big.
51	Brian	Like this [erases and draws a new arrow]
52	Andrew	Hell it was really hard to draw a map like this.

In the same way, Chris and Daniel need to learn the technique for measuring voltage and current in their electrochemical cell, as part of their effort to deal with the non-working electric fan:

53	Chris	We could check with this one [voltmeter/ammeter], if there's any…
54	Daniel	Right, if there's any…
[they ponder about the bubbles in the magnesium sulfate solution for 10 lines]		
55	Daniel	Okay, let's try uhm, where should we stick these in [leads]? Which one
56		should go into which [socket]? Ten, well. Well, it isn't more than ten
57		ampere, I think. Look at it, crazy, looks like…
58	Chris	Yeah but on this one it read, this one only read zero point one so…
59	Daniel	Yeah
60	Chris	[4 words missing]
61	Daniel	Nothing happens at all.
62	Chris	No. How should we actually measure this? Is it ampere?
63	Daniel	There it turned up.
64	Chris	One point eight, one point nine almost.
65	Daniel	Why does it read minus, what does that mean?
66	Chris	Not good. [turns the knob around]
67	Daniel	It reads like that [minus] on all sides.
68	Chris	Well I don't know.

In both cases, it is a matter of getting acquainted with the techniques of the practice. In each case they constitute ways of being able to proceed with the activity of reasoning about electrochemical cells. In the case of Chris and Daniel, they eventually get some help from the teacher, and manage to measure the difference in current between their electrochemical cell and the real battery provided:

69	Daniel	How many amperes do we have in our [electrochemical cell]? Zero. Zero,
70		zero, zero [turns the knob around]. How many amperes do we have in this
71		funny battery. Thirteen amperes, we've got no amperes, I mean, there's no
72		strength in our yucky current.
[…]		
73	Daniel	I see. That's why. Too little… to weak, or how do you say, to weak, to
74		little amperes.

Through this measurement they were able to make sense of the fact that the fan moves much easier with the battery than with their electrochemical cell.

4.3 Learning criteria for inclusion and exclusion

In both activities, the students had to establish relations to decide what aspects of the activity to include in their reasoning. In the next excerpt, Andrew succinctly states the generic problem of knowing what to include in the CM-activity (line 75):

75	Andrew	You don't really know what's important either. Or how to do it. I mean
76		perhaps we should include "Ions", since they've got a great part in this, but
77		it…
78	Brian	Yes. Well. Yes… ions.
79	Andrew	Third time a kick the stand [to the video camera]
80	Brian	Everything is "Chemical reaction". Or several chemical reactions perhaps.
81		Well, we can't include…
82	Andrew	No [laughs]
83	Brian	Uhm…
84	Andrew	"Electronegat…" No.
85	Brian	"Negative" and "Positive ions".
86	Andrew	"Plus-terminal"… is like… "Noble". We could've chosen that one. But
87		there's no room for it, kind of.

Andrew and Brian here construe several relations pertaining to norms for including or excluding certain terms in the CM. It seems, for example, as if they are implying both that terms applying too broadly to everything in the CM could be excluded (line 80) and that in any case, one cannot include all terms (lines 81 –

82). Furthermore, a term may be excluded because there is no space for it (lines 86 – 87). In the course of their reasoning, Andrew and Brian need to establish several such rules for inclusion and exclusion:

88	Brian	Do sulfate-"Ions" come in there?
89	Andrew	Yes.
90	Brian	Yeah. We can do like this. But then the "Glass filter" has to be included as
91		well.
92	Andrew	Like, through "Glass filter".
93	Brian	Heh [laugh], messy.
94	Andrew	Heh heh [laugh] No kidding.
95	Brian	There. Uhm, "Plus-terminal"… "From the 'Plus-terminal"…
96	Andrew	Yeah. Like… sulfate "Ions" move… through the "Glass filter" to the
97		"Minus-terminal".
98	Brian	Gee!
99	Andrew	But in fact I think, it's seems rather meaningless to add much more. Cause
100		it's only getting, like…
101	Brian	Yeah right. Heh [laugh] well, yeah.
102	Andrew	Yeah but I mean it's messy already, kind of.

They establish the norm that a good CM should not be too messy, and to the extent that adding more terms to it contributes to making it more messy, they might as well be excluded (lines 99 – 102). On the other hand, they also establish that including one term (sulfate ions, line 88) may require the inclusion of another term (Glass filter, lines 90 – 91). In the LW-activity too, Chris and Daniel learn norms for inclusion of the particulars and contingencies of the practice:

103	Daniel	Yes it… there's got to be a lot of copper on that one [copper electrode]. I
104		mean, more than before.
105	Chris	Yes. You can see that.
106	Daniel	Yeah, there.
117	Chris	Here there's much more copper color.
108	Daniel	Yes.
109	Chris	That we rubbed off.
110	Daniel	Cool.

In distinguishing copper on the copper electrode they establish a norm for accepting what they see as signs of a precipitation of copper, viz., in comparison with how the electrode looked like initially. Considering what they have been discussing before and how they express themselves in the excerpt (line 103), another norm for counting what they see as copper having precipitated is that theoretically, it *should* be there.

5 Discussion

Through the high-resolution mechanism for analyzing learning (Wickman & Östman, 2002) that we used in this study, we were able to point to some similarities between two settings normally considered to be very different. Our results support the notion that in laboratory work, students need to learn procedures and techniques as part of learning the science content (Psillos & Niedderer, 2002). But our results show that this was also an important part of their learning in the concept mapping activity. Åhlberg and Ahoranta (2004) claimed that students quickly learn how to construct good concept maps and Wandersee (2000) stated that it takes at least eight weeks for students to feel comfortable and improve their performance in a course. But it seems unlikely to assume that students will come to a state where they are only focusing on the conceptual issues of a new concept mapping task. It is more probable that the need seen in our results to fill different kinds of gaps in response to contingencies – even in the concept mapping activity – is something that students need to cope with in every new encounter (Hamza & Wickman, submitted).

From the point of view of concept mapping, our study indicates that "the processes with which students learn with concept maps" (Nesbit & Adesope, 2006) cannot only be studied from a purely cognitive, conceptual perspective. Kinchin (2001) observed that some studies on students' learning with concept maps have focused too heavily on the nature of their construction of valid links. He concluded that a focus on only the valid links may hide important aspects of the thought processes that lead a student along a certain path of understanding, because "'invalid' links may have a value to the student by supporting more valid links (sometimes temporarily)" (page 1260). Our results show that how students construe relations to fill gaps having to do also with the norms and techniques of the practice has consequences for how their reasoning develops.

From the point of view of laboratory work, the problem with students engaging in procedures and concrete material may be viewed, less as a problem particular to laboratory work, and more as a problem that arises whenever students engage in a task, even one alleged to be purely conceptual. So claims to the effect that laboratory work should be abandoned in favor of other activities, while still being possibly valid in content, cannot rest solely on the assumptions that laboratory work present students with its own, particular kind of problems. Our results indicate that there are similar problems facing students even in two activities being somewhat at the extremes of the theory – practice scale of teaching activities.

To conclude, some difficulties thought to be particular to practical work as it is normally conceived may constitute legitimate problems even in a task intended to turn students' focus toward conceptual issues. Studies of different teaching activities as methods or means for attaining certain learning outcomes construe the activities in terms of different effectiveness, either of different varieties of a method or between methods (Millar, 1991; Nicoll et al, 2001; Osborne, 1998). Although much has been learned through this approach, it may overlook important aspects of the learning processes going on in these activities. Åhlberg (2004) stressed that the use of concept mapping need not be restricted to the constructivist learning theories in which most studies of concept mapping are conducted. And Jiménez-Aleixandre & Reigosa (2006) successfully studied the contextualizing practices during student laboratory work. Viewing teaching activities also as situated practices in which students need to learn to participate may bring to the fore the process aspects of what constitute difficulties for students in these activities.

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