

of intertwined human and disciplinary agency'' (p. 141). What we add to the mix through the notion of accountability to others are the specific historically grounded communities in which research investigations or other forms of productive disciplinary engagement occur. It is not just that there is a dance of agency between the researcher and the material/disciplinary world, or a joint taking into account of their authorities. In addition, when researchers (or students in who learn to act like them) communicate about their investigations, they also need to be responsive to the ideas of the significant others in their research communities who are working on related issues. To ''account for'' how what one is doing makes sense in light of these prominent voices. This is another sense in which accountability, or the agency of those other than a particular researcher, comes into play.

Most importantly, although our account above of Pickering's dance of agency identifies alternating episodes in which the human researcher or the discipline has agency, I do not think that Pickering's theory necessarily implies that human agency is ever fully absent. As Pickering (1995, p. 117, emphasis in the original) notes ''The *point* of bridging as a free move is to invoke the forced moves that follow from it. Without such invocation, conceptual practice would be empty'' (p. 117). So, human researchers use their agency to create conceptual systems that they then choose to submit to forced moves from the discipline or the material world to learn something about the validity of those very conceptual systems. For example, as Pickering (1995, pp. 141, 142) clarified when discussing Hamilton and the quaternions, ''Here, once more, it is not the case that Hamilton as a human agent disappears from my analysis.... It is worth emphasizing that Hamilton evidently did exercise discretion in choosing just which disciplines to submit himself to.'' Later he notes that Hamilton ''both drew upon established routines to carry himself along, and as part of his accommodation to resistance, transformed those routines, eliminating or adding to them as seemed to him promising'' (p. 143). For these and other reasons, I view Pickering's dance of agency as one in which the human serves as the leader of the dance. So when a researcher lets an experiment run or makes use of pre-existing mathematical procedures, it is with a larger purpose in mind that centrally involves their own conceptual agency: to make progress on the researcher's own conjectures or theories, with the forced moves a crucial means for achieving those larger aims. This also resonates with Schoenfeld's (1998) analysis of what it means to really do mathematics through an analogy with cooking: as one moves from being a beginner cook to 'really cooking' (or really doing mathematics), one moves from attempting to slavishly following cookbook procedures to inventively adapting and combining them with each other to make new dishes or proofs (Greeno, 2006). Thus, in our interpretation of Pickering's (1995) theory, the dance of agency is not a leaderless dance. The researcher is the lead partner, with the disciplinary and material world participating crucially, but being shaped all the while by the researcher's purposes.

Some questions for Krange about the insulin gene case

Now having hopefully somewhat clarified our understanding of both Pickering (1995) and its relationship to our own work, it is a helpful time to return to the classroom case that Krange analyzes in her paper. I have many questions about it in part because I sensed from the text that Krange herself was of multiple minds about how to best interpret what the students and their teacher were doing and eventually accomplished in their work on the insulin gene task. Therefore most of our questions involve pointing out some of the different interpretations that I thought I read in her paper and asking her to comment on them.

Who is leading the dance of agency? With respect to Pickering's work (1995), Krange systematically identifies various specific free moves (bridging or filling) or forced moves (transcription) that the students made in completing the insulin gene task, which might be taken to indicate that a very similar kind of dance of agency is occurring in her case and those in Pickering (1995). However, well before the analysis begins, she carefully notes that there is a difference between Pickering's cases in which "new knowledge is about to be made" and hers in which the students "adjust to relevant knowledge, understand its characteristics, and use it during problem solving." I think this is a very telling point. Building on the discussion above, one might say that in Krange's case, the leadership of the dance of agency is reversed from the examples in Pickering (1995) as well as Engle and Conant (2002). Rather than disciplinary agency being a resource for the development of the researchers' conceptual agency, the students' conceptual agency might be serving as a resource for them being able to correctly embody the agency of a discipline (as represented by the designers of the instructional materials) in their own actions. In particular, it seems from Krange's analysis that the focus of the lesson is on having the students learn how to do the task of identifying which of a sequence of protein strings matches the one that can be read on a given insulin gene, a set of forced moves that are referred to in the instructional materials as gene sequencing. Different ideas of what the instructions mean by "sequence" (free bridging moves) are a resource for the group eventually finding the one interpretation that will allow the students to do this task correctly, but this set of free moves is not in and of itself the primary object (in the activity theory sense) of what the students are supposed to be doing. So although like Pickering, Krange successfully identifies when bridging, transcription, and filling occur, how these moves were put together indicates that a very different kind of dance of agency was going on. Is this what Krange meant to suggest on page 4 above? In either case, what might this mean for the nature of the practices that the students were engaging in?

In what sense is this case one of productive disciplinary engagement? As with Krange using Pickering's concepts centrally but then noting in passing that there are ways in which they might not quite apply, there might be a similar pattern in her paper's use of the notion of productive disciplinary engagement from Engle and Conant (2002). On the one hand, the students are referred to throughout the paper as participating in "productive disciplinary interactions," but at several points during the analysis Krange notes ways in which particular students became disengaged, in which their work diverged from disciplinary practices, and in which it was not productive. Therefore I would love to know more about how Krange would characterize the nature of the students' productive, disciplinary engagement.

With respect to engagement, I would be very interested in Krange's analysis about how deeply various students were engaged in the insulin gene task. The paper did not try to systematically address this, but it did note moments when particular students may have been disengaged in it (e.g. "Frederic...seems to be concentrating on something else"). To complement these analyses, it would be helpful to have further evidence to document when the students *were* especially engaged in this task. Did the students show any investment in the task that went beyond complying with what the teacher or website asked? Was there evidence of any emotionally laden investment as we saw with the orca controversy in Engle and Conant (2002)? How did the degree and nature of the students' engagement in this task compare with their engagement in the other tasks in this unit or in this classroom more generally?

With respect to the senses in which the students' engagement was disciplinary, I wondered how the DNA sequencing task that the students were doing relates to what is

involved in DNA sequencing in scientific practice. In our analyses of disciplinary engagement in both Engle and Conant (2002) and Engle and Faux (2006), we looked for parallels between students' practices and those of participants in the relevant discipline(s). So how is and has gene sequencing been done in scientific practice and in what ways does that relate to what the students' were doing? Were there ways in which the students' practices diverged from scientific practice, and if so, what may have been their origins? There are some references in the paper to divergences like when Krange mentions that only one of three questions students raised during excerpt six were "disciplinary based" and that the website's instructions made students read the gene in a particular way that was "arbitrary in a scientific sense." There was much less, however, about specific parallels with scientific practice. Given that, the impression I got was of a standard school-like matching task wearing the clothing of scientific terms and examples. Specifically, the students' task basically seemed to involve examining a complex diagram in order to see which of three pre-given sequences of letters could be found within it. That these letters represented nucleotides, or that the diagram is of an insulin gene did not seem to be crucial for solving the problem nor particularly attended to by the students (at least in the data presented in the paper). Perhaps this also relates to Krange's intriguing comment near the end of the paper that "it is not sufficient for students to be accountable according to disciplinary norms. They also need to be accountable in a more general sense to dealing with the available learning resources." Given all this, I would like to know much more about both the parallels and the discontinuities between gene sequencing as the students did it and as scientists do it. I also wonder how this particular classroom's practices of "doing school" might have shaped students' practices.

Our notion of "productivity" builds on the notion of disciplinary engagement in that it is a claim that there was documented progress over the course of a discussion with respect to particular disciplinary issues, practices, etc. Note that this is very different from saying that students were on the "right track" or got to the right answer from the perspective of the designer of the task. Thus, rather than saying that one part of a discussion was the productive part and the rest was not, we would instead call a whole discussion productive when students make significant disciplinary progress from its beginning to end. This can be illustrated by comparison with our analysis of Hypothesis Experiment Instruction (HEI) discussions (Engle, & Conant, 2002.). At first glance these discussions are similar to those of the insulin gene case as HEI lessons are also launched via a multiple-choice question. The difference is that students in HEI discussions pick different response alternatives to support, and they make progress over the course of the discussion by developing more disciplinarily grounded arguments for why each alternative does or does not make sense. In contrast, in the insulin gene case, it appears that the primary changes involve the students learning what they are supposed to do with the diagram of the insulin gene, and then doing it in order to identify which response alternative is correct. Although this is evidence for the successful completion of the task, I am less certain about the significance of these changes for the students' disciplinary understanding of gene sequencing. In fact, I suspect that Krange also questioned this herself when she commented that "while knowledge about the purpose of the design may have made it possible for the students to solve the given problem of sequencing the DNA molecule (the insulin gene) and to determine which of the three sequences is correct (see Fig. 2), it did not insure a better understanding of sequencing as a knowledge domain. Ultimately the tools may be considered as hindering rather than encouraging the students' conceptual practices."

So overall, given the evidence presented, I am unclear about how the insulin gene discussion does and does not provide evidence of productive disciplinary engagement. I

therefore look forward to any further evidence and analyses that Krange can provide to help address this issue.

In what ways and to what degree are the Engle and Conant (2002) principles embodied in the case? Given I am unclear about the status of the insulin gene case with respect to productive disciplinary engagement, it does not make sense at this juncture to get too deeply into explanatory analyses of how each principle may or may not have been embodied in the case, though I expect them to be helpful. However, we will make some quick comments that will hopefully be helpful for that work, whether it turns out that this is a case in which it occurred like the cases in Engle and Conant (2002) or one in which it fell short like those in Engle and Faux (2006).

First, we found the fact that Krange analyzed the embodiment of the principles person-by-person and moment-by-moment very compelling. In Engle and Conant (2002), we looked at their embodiment over time, but only with the group as the unit of analysis. Like Krange, we are discovering in a re-analysis that we can get a much more nuanced view of what is going on by also considering differences between individuals (Engle, McKinney de Royston, Langer-Osuna and Bergan, to appear). To help readers better able to see patterns in her careful person-by-person analysis, it would be immensely helpful if Krange could provide a chart or other summary device (like the very useful Fig. 5) that captures in one place how each participant was involved in embodying each principle.

With respect to problematizing, I agree with Krange that there was a lot more potential for it during the early episodes. Specifically, I saw particularly notable attempts to problematize in: Cornelia's questions about what sequence means in turns 6 and 20, her question about the switch to sequences of three rather than two letters in turn 18, Fredric's question about which way to read the gene in turn 23, and Mark's question about how they can know which sequence is the correct one in turn 24. However, in my interpretation, all four of these student efforts to problematize the activity seem to have been either ignored or squelched, at least initially. For example, in the case of Cornelia's key question about what it means to "sequence," the students did not propose any of their own ideas; instead they consulted authoritative sources. Fredric read from the website (turns 7, 9), the teacher used her authority to provide her own interpretation (turn 10), Fredric suggested the library (turn 13), and the teacher suggested the dictionary (turn 21). The same occurred with Frederic's question. Finally, both Cornelia's question about the number of letters and Mark's about how to know if a given sequence is correct appear not to have been taken up. Given the specification of the article of the various steps to solving the problem that the students have to do and how they rely so strongly on instructions and other constraints provided in the website, it becomes less surprising that there was less space for the students to problematize what they were learning about. And in fact Krange later mentioned that the teacher "closes discussions...prevent[ing] the students from raising unnecessary, new knowledge-oriented questions," indicating that she may have also come to view the students' problematizing as being strongly constrained by other authorities.

With respect to authority, in addition to the issues I have already raised around the dance of agency, I noticed that Krange does not mention in her analysis any of the other senses of authority (stakeholders, contributors, or local authorities) that we analyzed in Engle and Conant (2002). I am guessing that this is because she does not believe they are embodied in the insulin gene case, but would be very interested whether this is indeed her view. I would be especially interested in her perspective on the issue of whether the students were positioned as *stakeholders* with publicly recognized ideas during the discussion as this is an issue for which we provided some potentially helpful analytic

machinery (see Engle & Conant, 2002), and have also built upon in our current work on generative learning (see Engle (2006) as well as comments on it by Greeno (2006)).

With respect to accountability, in our use of the idea someone is accountable to the discipline because they regularly explain or 'account' for how what they are doing relates to disciplinary norms and ideas. So, following Krange and Stenning et al.'s (2002) use of "authorizing" for "authority," perhaps this principle could be called "accounting" instead. In any case, such accounting can be a means through which particular people become recognized as knowledgeable authorities, but it is not the same thing. Similarly, accountability to others would be shown when students account for how their ideas relate to those of others who are addressing some of the same questions. Therefore additional analysis would have to be done to examine whether and how different students and the teacher held themselves accountable in these senses. I would be very interested in the outcome of such analyses as they would help us better understand how these different senses of accountability relate to each other.

Conclusion

In conclusion, I found Krange's paper very stimulating. It helped me think much more deeply about how my and my colleague's ideas might be usefully combined with those of two other researchers whose work we greatly admire. In addition, it has provided a great opportunity for me to clarify several points we were trying to make in earlier articles. But most of all, I hope this commentary will prompt further discussion with Krange herself about a very interesting case that, among other things, challenges us to better understand how school-based practices relate to scientific ones.

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Sociocultural perspectives on learning⁴

Ingeborg Krange

Thanks to Lisa M. Bouillion and Randi Engle for spending time not only reading but also developing thorough comments related to different issues raised in my article “Students conceptual practices...” (Krange, this issue). Over the next pages I pick up some of these themes to hopefully continue the discussion a bit further. Issues are pragmatically selected as to what I have felt manageable within this relatively short text, and I hope that we later not only will have occasions to pursue these but also the ones I have not included here.

The temporal dimension

I will argue, in line with Bouillion that within sociocultural perspectives on learning the issue of time is an essential one. It allows focusing on “the cultural means that mediate interactions in the world and in ways which those means—material or representational—are taken up and adapted over time” (Bouillion, this issue). I would like to discuss some of the issues she raises a bit further.

First, Bouillion suggests including activity theory (Engeström, 1987) to further explain the observed patterns of participation. She underlines the importance of bringing in a wider context to better understand in what ways current interactions are connected to a history of prior interactions, community rules and division of labor. This is an interesting suggestion but at the same time it affords a different kind of interpretation than what I offered in the article published in this issue. I would argue that there are at least two different ways to interpret time in socio-cultural views of learning; moment-to-moment interactions that emphasize intersecting means in a vertical sense and structural conflicts that follow a more horizontal line of interpretation and that focus on a chronological pattern of thesis, antithesis, and synthesis. What I did was to use the former of these. I used the dimension of time to consider how intersecting means in a vertical sense were expressed in excerpts of the students’ interactions and at the same time study how these changed over time in a horizontal sense. I would like to emphasize that it is the vertical analysis that constitutes the figure in analysis while the horizontal aspects constitute the background against which the vertical changes become more visible. Within an activity theoretical framework this relationship is more or less reversed since detailed evolving interactions only would serve

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