Documenting and Interpreting Ways to Engage Students in 'Thinking Like a Physicist'

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Abstract. The Paradigms in Physics Program at Oregon State University has adapted a variety of interactive pedagogies to engage students in 'thinking like a physicist.' Video recordings of class sessions document what the students and instructor say and do. This paper discusses development of narrative interpretations of such videos. Examples are drawn from two detailed narratives of activities during which the main ideas emerged during the wrap-up discussions rather than during the tasks that the students had been doing in their small groups. The goal of these 'compare and contrast' wrap-up discussions was to help the students envision connections among geometric and algebraic representations of the mathematics they would be using during the coming weeks of instruction in quantum mechanics. The purpose of the narratives is to provide examples of wrap-up discussions with commentary about ways in which the instructor was choosing to guide this process.

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INTRODUCTION

What does it mean to engage students in 'thinking like a physicist'? How can instructors learn how to do this? How can instructors who are attempting to do this share their successes and challenges with others?

One approach to addressing these issues is to develop narrative interpretations of videos of class sessions that seem to be good examples of engaging students in 'thinking like a physicist.' The intent is to help interested instructors envision an interactive classroom culture, one in which students learn by talking with one another about what they think as well as by listening to and conversing with their instructor. This approach to documenting and interpreting learning experiences draws on the power of narrative to convey cultural values and practices.[1]

In constructing the narrative interpretations, the first author built upon her teaching experiences and research in the tradition of ethnography of communication (Philipsen & Coutu, 2004; van Zee & Minstrell, 1997). Ethnographers of communication examine cultural practices by interpreting what is said, where, when, by whom, for what purpose, in what way, and in what context. The interpretative narratives present examples of an instructor welcoming students into the culture of 'thinking like a physicist.'

The Paradigms in Physics Program at Oregon State University has adapted a variety of interactive pedagogies to foster student thinking.[2] In this paper, we present excerpts from narrative interpretations of two discussions from classes taught by the second author during the first week of the winter term of the junior year sequence. In developing these narratives, we viewed videos of the class sessions together, discussed aspects that seemed of interest, and embedded these reflections in the transcripts as we spoke together. The first author then crafted the narratives from the transcripts and reflections.

We begin by describing typical class sessions. Next we present excerpts from two narratives of 'compare and contrast' wrap up discussions. We conclude with implications.

TYPICAL CLASS SESSIONS

As students enter the classroom, each picks up a small whiteboard (roughly 12" x 18"), marker, and cloth for erasing. They sit in groups of two or three at rectangular tables. Class typically begins with Corinne speaking to the students, writing on the blackboard, and perhaps using props to visually demonstrate some concept or process. She also includes the students in the thinking, however, by asking questions and welcoming contributions. She also may gauge students' understanding by asking them to write responses on their small whiteboards and to hold their whiteboards up for her and others to see. In addition, she may collect some of the small whiteboards and use them to ground development of particular concepts within students' ways of thinking.

During small group activities, members of each group write on a larger whiteboard that covers most of the table at which they work. Writing on the large whiteboard fosters collaborative problem-solving by providing a shared focus for the group members' discussions. Instead of writing separately and silently in their notebooks, they work through their group's problem together by discussing what they are recording on the whiteboard. Through these conversations, and later presentations of their work to the class, the students gain experience in articulating their own ideas while starting to speak the specialized language they will need to use as practicing physicists.

As Corinne and the graduate assistant move from group to group to offer assistance as needed, they can glance at the large whiteboards to see where the small groups are in their thinking. By engaging a group in conversation, Corinne can shape the group's progress while becoming aware of the difficulties and successes being experienced by these particular students. She then uses such knowledge in facilitating the subsequent wrap-up discussion.

'COMPARE AND CONTRAST' WRAP-UP DISCUSSIONS

During a wrap-up discussion, Corinne guides students in thinking together about challenging aspects of a topic that they have just explored through a small group activity. The examples presented here are 'compare and contrast' wrap-up discussions in which the main idea emerges during the discussion rather than during the task that the students have been doing in their small groups. During such discussions, the take-home message usually comes in examining the similarities and differences in what the different groups did and found. Thus the function of the wrap-up discussion is to develop new understandings. This contrasts with the traditional laboratory session in which the main concept to be learned is illustrated in the task and if a wrap-up discussion occurs at all, it is to verify that the students obtained the expected result.

The two wrap-up discussions illustrated here occurred during the second and fourth days in a week of instruction known as the 'Preface.' The purpose of the Preface was to engage junior-level physics students in reviewing, and in some cases learning for the first time, the linear algebra they would need to use while studying quantum mechanics during the winter term. The goal of these 'compare and contrast' wrap-up discussions was to help the students envision connections among geometric and algebraic representations of the mathematics they would be using during the coming weeks of instruction.

Day 2: Representing Transformed Vectors Graphically

The first class of winter term had been a 50-minute interactive lecture. Corinne had introduced/reviewed basic matrix manipulations such as multiplying matrices and calculating determinants.

Day 2 was a double period. First the students worked in small groups. Each group used a different given matrix to transform a common set of given vectors and then plotted the transformed vectors graphically. In this activity, the small groups were all doing essentially the same calculation, to multiply their matrix times this standard set of vectors to find out what their matrix did, and also to figure out what the determinant was. Thus, when each group reported, everybody in the class understood in principle the calculations the group had done, so the wrap-up discussion could focus on the similarities and differences in the results for the different matrices rather than on the mechanics of the calculations.

Corinne had carefully chosen most of the matrices to represent simple transformations of vectors by matrices with real numbers, e.g. rotation by $+\pi/2$. She had also chosen a more generic matrix such that its own entries were real and integer and the components of its eigenvectors also were real and integers. The given vectors included the (real) eigenvectors of all these matrices although students were not informed of this fact ahead of time.

The real purpose of this activity was to get students to recognize conceptually that an eigenvector is a vector whose direction is not changed when multiplied by a matrix but she wanted the students to come to their own realization that that concept is important. So in the set of directions, she indicated that the students would be discussing the determinant and what it means, which could be an interesting and possibly in the long term fruitful distraction, and she stated almost as an aside that she wanted them to say if there were any vectors that were not changed by the transformation.

In constructing the narrative, we divided this wrap-up discussion into the following segments:

- Initiating the Wrap-up Discussion
- Discussing Rotation by $+\pi/2$: Group 1
- Discussing Rotation by $-\pi/2$: Group 2
- Discussing Reflection along $y = x$: Group 3
- Developing an Hypothesis: Group 4

- Interpreting a Transformation as a Reflection or Rotation: Group 5
- Interpreting the Meaning of 'Change in Direction': Group 6
- Considering a Matrix with Elements Larger than 1: Group 7
- Participating in the Hypothesis Making Process: Group 8
- Considering the Validity of a Hypothesis: Group 9
- Interpreting a Determinant of a Matrix Equal to Zero: Group 10
- Jointly Constructing a Review
- Providing an Overview of the Coming Sessions

Each segment of the narrative presents excerpts from the dialogue and Corinne's reflections. The segment about Group 1's presentation, for example, quotes what the presenter said, Corinne's response, her reflection, and a sequence of her exchanges with the presenter about his use of language in discussing determinants. Next the narrative quotes Corinne addressing the class as she explicitly articulated the difference between this course and many others: "What I want us to be thinking about is, I want us to do some physics the way it's really done. A lot of education is sort of about giving you a really polished presentation, telling you what it is you should expect…but that is not how people do physics."

Corinne then welcomed the students into the culture of physicists by stating how physics is done and how they would be doing physics right now during this discussion: "People do a lot of different examples and then they see if they can find something in common from all those examples so what I want you to think about is: Can we figure out anything about what the determinant is telling us about the matrix? So does the determinant tell us anything? So here's an example where the determinant is one. Okay? Let's just remember that for now."

In reflecting upon this statement, Corinne commented that she wanted the students to experience what it is like to deduce a result from looking at many examples - the experience that many professional theoreticians have. This conversation was all about helping set them up for that expectation. She was trying to get the students to experience what it is like to be a theoretician. In most classrooms, students experience theory as they are being told what the theory is but that does not help them understand what it means to come up with new theories. In this activity, her experience has shown that the students often have been taught how to find the determinant but they typically do not have any idea of what the determinant means geometrically. As they were going through the different examples in this activity, she was giving them an opportunity to 'theorize' from the different examples what the geometric meaning might be.

Day 4: Solving for a Matrix's Eigenvalues and Eigenvectors Algebraically

The third day had been a 50-minute interactive lecture during which Corinne presented properties of rotation matrices in two and three dimensions. Day 4 was another double period. Its focus was a set of linear algebra problems that Corinne had designed to illustrate nuances in solving for the eigenvalues and eigenvectors of matrices. She had demonstrated a straightforward example in a brief lecture and then had used a small group activity to give the students experience with exceptional cases that were trickier, particularly those involving degeneracy. The small groups had worked on different problems and were presenting their solutions to the whole group during the wrap-up discussion.

The goals of Day 4's small group activity and wrap-up discussion were for the students to learn an algebraic procedure for finding eigenvalues and eigenvectors for a matrix and to see that the vectors that they were getting from their algebraic calculations were the same ones that they had seen to be unchanged when plotted graphically on Day 2. By comparing and contrasting the solutions presented during the wrap-discussion, the students could gain a deeper understanding of the relations between geometric and algebraic representations of eigenvectors. During their study of quantum mechanics in the weeks ahead, Corinne wanted the students to understand that finding eigenfunctions for the Hamiltonian would mean looking for the functions that are unchanged or just scaled by a constant.

In constructing the narrative, we divided this wrap-up discussion into the following segments:

- Initiating the Wrap-up Discussion
- Calculating and Representing Complex Eigenvalues and Eigenvectors: Group 1
- Representing a Generalized Sense of Direction: Group 2
- Monitoring Algebraic Accuracy and Interpreting a Result: Group 3
- Noticing and Defining Degeneracy: Group 4
- Interpreting Diagonal Matrices: Group 5

The presenter for Group 4 began in the same way as the others, by identifying the matrix his group had used, "Our matrix was negative one, zero, zero, zero, negative one - this thing here" he finally said as he pointed to a three by three matrix with zeros everywhere but on the diagonal. Corinne took this opportunity to coach his use of language: "Lots of times people, if they have a matrix that has things only on the diagonal, instead of saying minus one, zero, zero, zero, minus one, you got tired right? and quit in the middle? <yeah> <laughter> which is what everybody does. If it's just diagonal, the convention is to say it's diagonal and you just read off the diagonal ones, and then everybody knows its diagonal."

While reflecting upon the video, Corinne noted that there are so many new concepts at this level that the students do not know how to articulate them clearly for themselves and so in the classroom she does a lot of talking, but in response to what students say - here's a way of saying this, there's a way of saying this, try phrasing it this way. This active shaping of ways of speaking could occur because she provided many opportunities for the students to do the talking.

The presenter accepted her suggestion and stated, "It's diagonal, with one, negative one, one." When she asked him how that compared with the previous matrix, he answered immediately, "It's the same matrix except it's three by three with a one," and pointed to the one in the bottom right corner. Corinne confirmed his response, "So that upper left corner is the same as what [Student J] just did," and stated explicitly the reason for her decision, "That's why I wanted to do this one next."

At this point, Corinne addressed the entire class, "Okay. Now. So what do you all expect here? Do you have any expectations?" In reflecting upon these questions while watching the video, Corinne noted that although these questions match what she had asked at this point in the earlier presentations, she apparently also was wondering them for herself, as an instructor thinking aloud in the moment, pondering whether or not her students would have any expectations for this matrix. After several students responded, she asked for a repeat, "What are you saying, say that again, what do you expect to happen along the z axis?" and a student replied, "Nothing." "Nothing," Corinne confirmed, "you expect the z axis to be unchanged" and picking up on another student's comment, she exclaimed, "and therefore you expect it to be an eigenvector, yes!"

The presenter for Group 4 then articulated an inference he was making based upon the previous student's problem, "If I didn't do this beforehand and then I saw hers," while pointing to the previous student's whiteboard, "and then I started to do this, I'd expect one of my eigenvalues to be their eigenvalue, that's what I'd expect." This was exactly the kind of thinking that Corinne was attempting to nurture and likely occurred because this student had already made the connection between his matrix and the one discussed previously. The video record documented the members of this small group interacting with one another during Group 3's presentation when they had realized that the matrix under discussion then was contained within their own.

IMPLICATIONS

Instructors interested in using the small group activities described here might choose to read the detailed versions of these narratives (37 single-spaced pages!) and to watch the videos.[2] The wrap-up discussions illustrated here occur differently every year, however, even though Corinne uses the same vectors and matrices. Thus the narratives are not intended to serve as scripts but rather as ways for interested instructors to add to their images of what engaging students in 'thinking like a physicist' looks like in particular contexts. The methodology used to produce the narratives can be adopted readily by others with video capability and sufficient miking so that students can be heard on the videos. Transcribing requires patience and the collaborative sessions require considerable time but the process of developing narrative interpretations is straightforward: watch the video together, pause at interesting moments, type the reflections directly into the transcript, and later render these as a narrative. Such narratives in a variety of contexts and settings could add to the resources interested instructors consult in shifting toward more interactive practices.

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1. Information about the Paradigms program, including the activities, narratives, and video discussed here can be found at: *http://physics.oregonstate.edu/portfolioswiki*
3. See, for example, G. Philipsen, G. & L. Coutu, "The Ethnography of Speaking" in *Handbook of Language and Social Interaction* edited by K. L. Fitch & R. E. Sanders, Mahwah, NJ: Lawrence Erlbaum, 2004, pp. 355-380; E.H. van Zee, E. H. and J. Minstrell, "Using questioning to guide student thinking" *The Journal of the Learning Sciences*, **6,** 229-271(1997).