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Postprint

This is the accepted version of a paper published in *African Journal of Research in Mathematics, Science and Technology Education*. This paper has been peer-reviewed but does not include the final publisher proof-corrections or journal pagination.

Citation for the original published paper (version of record):

Linder, A., Airey, J., Mayaba, N., Webb, P. (2014)

Fostering Disciplinary Literacy? South African Physics Lecturers' Educational Responses to their Students' Lack of Representational Competence.

African Journal of Research in Mathematics, Science and Technology Education, 18(3): 242-252

<http://dx.doi.org/10.1080/10288457.2014.953294>

Access to the published version may require subscription.

N.B. When citing this work, cite the original published paper.

Permanent link to this version:

<http://urn.kb.se/resolve?urn=urn:nbn:se:uu:diva-232185>

Fostering disciplinary literacy? South African physics lecturers' educational responses to their students' lack of representational competence

Anne Linder^{1*}, John Airey¹, Nokhanyo Mayaba² and Paul Webb²

¹ *Department of Physics and Astronomy, Uppsala University, Sweden*

² *Faculty of Education, Nelson Mandela Metropolitan University, South Africa*

**Corresponding author. Anne Linder, Department of Physics and Astronomy, Uppsala University, Sweden. Email: anne.linder@physics.uu.se*

Abstract

Recently, the South African Institute of Physics undertook a major review of university physics education. The report highlighted the necessity for further transformation of the teaching of physics, particularly in relation to the teaching of under-prepared students.

In this article we examine how physics lecturers in South Africa reported how they respond to the teaching challenges that they face in terms of representational competence. We argue that the goal of any undergraduate degree is the production of disciplinary literate graduates, where disciplinary literacy refers to the ability to competently deal with the various representational formats used within the discipline. For physics the development of disciplinary literacy involves competence in a wide range of representations, such as; written and oral languages, diagrams, graphs, mathematics, apparatus, simulations, etc.

Our interest in this study was the way in which individual physics lecturers described how they deal with their students' lack of representational competence. To this end, we interviewed 20 physics lecturers from five purposefully selected representative South African universities about their students' lack of representational competence and the educational strategies they use for dealing with this problem. These interviews were transcribed verbatim and analysed for potential patterns.

Iterative, interpretive analysis resulted in the identification of six qualitatively different response strategies that South African physics lecturers indicate they invoke to deal with their students' lack of representational competence. We suggest that an understanding of this range of possible response strategies will allow physics lecturers to better understand their own responses and those of their peers, and that this, in turn, may lead to changes in educational practice.

Based on the differences in individual response strategies that we find, we further argue that inter- and intra-faculty discussions about undergraduate disciplinary literacy goals have the distinct potential for reforming South African undergraduate physics. Here, we suggest that the disciplinary literacy discussion matrix that we used to initiate dialogue in our interviews may also double as a useful starting point for such faculty discussions.

Keywords: university physics, representational competence, disciplinary literacy, lecturers' response strategies

Introduction

The question of whether higher education is meeting the needs of contemporary students is of international importance and in the case of science subjects such as physics, this question has

particular significance for South Africa. In an attempt to evaluate current university physics education the South African Institute of Physics recently undertook a review of the undergraduate physics education being offered (CHE-SAIP, 2013). Two of the central themes in the report are the necessity for further transformation of university physics teaching (p. 14), and the need for further research, particularly in the area of teaching under-prepared students more effectively (p. 34). In order to do so, we see the way in which physics departments and individual lecturers adapt their teaching practices to respond to the competencies of their students as being critical. Whatever the level, the educational responses of physics lecturers will be dependent on two parameters: their perceptions of their students' competence and the educational goals that they are attempting to meet. We address both of these issues from the perspective of disciplinary literacy (Airey, 2011a).

Fostering disciplinary literacy: the goal of undergraduate education

It has been argued that the goal of any undergraduate degree program may be framed in terms of *fostering disciplinary literacy*, which we relate to achieving representational competence. Building on Gee's (1990) notion of 'big D Discourse', Airey (2011a) has defined disciplinary literacy as *the ability to appropriately participate in the communicative practices of a discipline*. It is important to point out that the use of the term *communicative practices* could be taken to include *knowledge production and dissemination*. It would then become a subset of Gee's modelling of social identity, which also includes other aspects, such as, gender, social status, group dynamics, power, culture etc. These aspects, though important, are specifically not part of the definition of disciplinary literacy that we are using. This is because the grounding focus of the definition was on the analysis of the representations that a discipline, like physics, offers students (Airey, 2011a). Here, disciplinary literacy involves an understanding of the ways in which knowledge is produced and disseminated within a given discipline. From this perspective, undergraduate learning involves becoming competent in the interpretation and production of disciplinary knowledge.

Using this perspective, we argue that the development of disciplinary literacy in undergraduate physics presents a major challenge to students, even before factoring in issues such as student under-preparedness and the cultural and linguistic diversity of the South African situation. We take this view because of the wide range of communicative practices that characterise the construction and communication of physics knowledge. Here, Lemke (1998) has convincingly illustrated how disciplinary literate physicists integrate information across a range of representational formats:

We can partly talk our way through a scientific event or problem in purely verbal conceptual terms, and then we can partly make sense of what is happening by combining our discourse with the drawing and interpretation of visual diagrams and graphs and other representations, and we can integrate both of these with mathematical formulas and algebraic derivations as well as quantitative calculations, and finally we can integrate all of these with actual experimental procedures and operations. In terms of which, on site and in the doing of the experiment, we can make sense directly through action and observation, later interpreted and represented in words, images, and formulas.

(Lemke, 1998, p. 7)

The idea of disciplinary literacy as we have presented it is an integral part of how we characterise representational competence in physics.

Representational competence in physics

The notion of representational competence that we used for our study is underpinned by the epistemological position that disciplinary ways of knowing and their associated working practices are inseparable from the representations used to communicate them (Airey & Linder, 2009; van Leeuwen, 2005; Lemke, 1998). Representational competence then becomes about the ability to effectively and appropriately both communicate physics knowledge and carry out its working practices.

It has been argued by many researchers that, in order for students to gain meaningful access to physics knowledge, they need to develop competence in the various representational formats used in physics. Here, physics education research has been carried out on many of these representational types, for example; mathematics and equations (Domert, Airey, Linder & Kung, 2007; Ragout De Lozano & Cardenas, 2002; Sherin, 2001), graphs (Aberg-Bengtsson & Ottosson, 2006), gesture (Scherr, 2008), diagrams (Fredlund, Airey & Linder, 2012; Rosengrant, van Heuvelen & Etkina, 2009), language(s) (Airey & Linder, 2006, 2011; Brookes, 2006) and video simulations (Eriksson, Linder, Airey & Redfors, 2014). A great deal of research has also focused attention on the integration of these individual representational formats and the ways in which students learn to move ‘fluently’ between them (e.g. Airey, 2009; Airey & Linder, 2009; Dufresne, Gerace & Leonard, 1997; Kohl & Finkelstein, 2008; Kohl, Rosengrant & Finkelstein, 2007; Meltzer, 2005; Rosengrant, Etkina & van Heuvelen, 2007; Tang, Tan & Yeo, 2011; van Heuvelen, 1991; van Heuvelen & Zou, 2001). Fredlund et al. (2012) have argued that the different representations have different disciplinary affordances, that is, they are designed to do different work in physics. In this respect, Airey and Linder (2009) claim that there is a critical constellation of representations that is necessary for a holistic understanding of any given disciplinary concept. Thus, for this article we frame the issue of the needs of physics students in terms of representational competence.

Research question

Given our interest in how, from a disciplinary literacy perspective, South African physics lecturers meet the needs of their students, our research question is as follows:

When South African physics lecturers perceive a lack of representational competence in their students, what are their response strategies?

Methodology

The work reported on in this article forms part of a larger comparative study of the disciplinary literacy goals of physics lecturers in Sweden and South Africa. Thus, in order to facilitate comparability, the procedures used in our study were almost identical to those used in the Swedish study (see Airey, 2012). In addition, however, our study also required approval from the ethics committee of the South African university from which the research was undertaken.

Data collection

Interviews were carried out with 20 lecturers from physics departments at five South African universities. The participating universities were purposefully selected so that their student intake typically represented a cross-section of different linguistic, socio-cultural and ethnic backgrounds. All the physics lecturers interviewed were volunteers and had signed a standard consent form that had been passed as part of the ethics approval process. The aims of the study were described and it was explained that the lecturers themselves, the courses they taught, and their universities would not be identified. A disciplinary literacy discussion matrix (Airey, 2011a) was then used to initiate dialogue and served to loosely configure our semi-

structured interviews (Creswell, 2009). This matrix is given in Appendix A. It consists of a number of cells that can be ticked for various physics representations (e.g. graphs, tables, diagrams, equations, English language, etc.) across three categories: Physics, Job, and Society. The lecturers were asked, *with respect to a course that they were currently teaching*, to tick those representations where they felt their students needed to develop representational competence. As part of this introductory phase, the interviewer clarified what was meant by representations using typical physics examples, and then went on to clarify what was meant by representational competence.

Empty rows were available for the lecturers to add other representations such as computer visualizations and other languages. Further, for each representation the lecturer could choose the type of representational competence required—interpretive or generative, i.e., if they felt their students only needed to be able to “read” the disciplinary knowledge presented by the representation, or whether they also needed to be able to produce the representation themselves. Taking the filled in disciplinary literacy discussion matrix as a starting point, the lecturers were asked, using the physics specific representations that they had introduced from a course that they were currently teaching, to describe why they had ticked the cells that they had and why they had chosen to leave other cells blank. This process was intended to clarify what was meant by representational competence. The discussion then moved on to how in practical terms, the lecturers matched these goals to the lack of representational competence of their students. The interviews lasted between 30 and 60 minutes each. These were digitally audio-recorded and then later transcribed verbatim.

Analysis

Our analysis involved developing categories to characterize qualitative differences in the lecturers’ descriptions of how they reported dealing with the lack of representational competencies that they saw their students coming to class with – what we are calling the lecturers response strategies. The categories were then formed by transcribing all of the interviews verbatim and then using the constant comparative method that is commonly used in interpretive studies (O’Connor, Netting, & Thomas, 2008). The process called for much iteration with cut out parts of the data transcripts repeatedly being compared to other transcript parts, and then back to whole transcripts, until no further changes evolved in the category development; in other words, until saturation occurred (Bogdan & Biklen, 1992). The iteration process also involved highlighting any practical, theoretical, descriptive and critical groundings that emerged from the transcripts.

Results

Our analysis resulted in the identification of six response strategies employed by South African physics lecturers when they perceive a lack of representational competence in their students. These six response strategies are:

1. Not relevant
2. Relevant, but not my job
3. Avoid problematic representations
4. Encourage translation to alternative representations
5. Offer passive support
6. Actively engage with the problem

The essential features of these strategies are now described and illustrated using transcript excerpts. Before proceeding, it is important to point out that; firstly, the excerpts are not

intended to fully reflect all of the attributes that make up a strategy, but to illustrate some central aspects of it and, secondly, we are not suggesting that a lecturer would only evoke one of these responses, rather these were the range of responses that we identified.

Response Strategy 1: Not relevant

Whilst appreciating the problems students had with some representational formats (chiefly oral and written languages) some lecturers argued that these particular skills were irrelevant to the task of learning physics.

In physics it's mostly mathematical calculations so the language doesn't matter much.

Language of physics is maths.

[when] doing classical mechanics, doing writing is pretty unimportant...

As can be seen from the quotes, the cases where lecturers used this strategy were specific and language-related.

Response Strategy 2: Relevant, but not my job

The second response strategy to a perceived lack of representational competence is to claim that meeting the students' lack of competence in that particular representation is someone else's job.

As a physicist I'm not there to solve the problem of the maths. They must be able to understand the maths sufficiently at that level and know why ... I'm not there to teach maths, they must go to the maths department if you need to learn it.

Scientific language is something that someone who is reasonably intelligent can pick up ... so my own feeling is if I can do it others can do it.

Here we can see that in the first example the responsibility for meeting the students' lack of representational competence is framed as the mathematics department's job and in the second example it is seen as the student's own responsibility. Another common related theme mentioned by lecturers was that the secondary schools should be training students better before they arrive, i.e. that this should have been the job of the school (cf. the discussion of under-prepared students in the introduction to this article). However, we decided to exclude such descriptions from this category since they could not be framed in terms of a lecturer response strategy. Rather we take such narratives as a manifestation of part of the problem itself.

Response Strategy 3: Avoid problematic representations

Many of the lecturers talked about avoiding particular types of representation that they knew from past experience would be difficult for their students:

Sometimes there is a wordy problem in the book, then I think well I have to think about what they mean here and then I tend to avoid that question. (avoid reading)

The writing skills we encounter are very bad and they are so bad that I hesitate to give any questions on an exam that require a written response because I usually don't understand that response ... just as valid for first language speakers as for non-first language speakers. (avoid writing)

Here again we see that language (in terms of reading and writing English) is seen as a representational problem for students and, when using this strategy, it is something that is to be avoided where possible.

Response Strategy 4: Encourage translation to alternative representations

As an extension and partial solution to the problems in the previous response strategy, response strategy 4 encourages translation from the problematic representation to other representations:

What I try to do ... is give the students a question and say to them, 'make a little sketch of the situation - of the physics involved'. ... make a little sketch, draw a diagram illustrating [the physics] ... [Students] read things and then they don't understand, and sometimes it just helps to do that – that's what I do in my physics: draw pictures and then translate it to mathematics.

Even in the exams I've had students ask what does that mean? So they understand the question but not a specific word so then I explain it to them right there. So the idea is not to catch them out, but to test their knowledge of the subject, so if language is the barrier then I must bypass that barrier.

... you get these jargon words and then I try to use the correct words, especially in exam papers, but if there is a more or less equivalent synonym I put that in brackets afterwards.

Equations can be complicated expressions, which don't tell you very much and then you can use tables and plots, which give you insights and allows you to see limits.

That's why I know I need to be present when my students write a test or an exam so if there is any question I can explain.

There were a large number of lecturers who adopted this response strategy. We suggest that this is perhaps unsurprising since a common theme in physics is that problems that are difficult/impossible to solve in one system are routinely translated to another system that is easier to deal with.

Response Strategy 5: Offer passive support

This response strategy involved setting tasks for students in order to help them structure their representational competence:

... the students have good textbooks ... and one would learn by reading these so it's important for them to read a lot because you pick it up ...

The students are instructed to read through the weeks prac. [laboratory experiments] before they come to the lecture.

... to help, give notes as well, not notes in the sense of doing much physics, but as a guide to the [physics in the] book.

The underlying theme of this category is that students are given support to develop the required representational competence themselves without active guidance or interaction.

Response Strategy 6: Actively engage with the problem

The final response strategy employed by South African physics lecturers involved actively engaging with the problem:

Maybe he needs background on these topics, take differentials; you don't take it for granted that they know. Because of time constraints I invite them in their free time, then I brush up on the maths.

In the context of problem solving, we emphasize that they need to understand the problem, so we need to unpack it [together].

Get them to view the maths as a tool to model the data and spend a lot of time emphasizing why we want them to do it in a particular way.

Here it is the lecturer who takes responsibility for actively engaging with the students as a way of responding to their lack of representational competence. This included some of the lecturers describing how they were involved with initiatives that they referred to as 'bridging programmes', 'academic support programmes', and 'extended programmes'.

Discussion

The six strategies that we have identified, and which were equally distributed across the five participating universities, are pragmatic responses to the day-to-day problems of student representational competence that South African physics teachers face. As such, we argue that it is conceivable that the same individual could usefully employ all of these strategies from time to time depending on the specific situation. However, this clearly does not mean that all six strategies are equally effective from the perspective of developing disciplinary literacy. Also, since we are interviewing the teachers about their teaching strategies, it would have been possible to frame the study in terms of Shulman's Pedagogical Content Knowledge (PCK) and the body of work derived from this. However, had we used the '2012 Personal PCK Consensus Definition' (Gess-Newsome & Carlson, 2014), response strategies 1 and 2 would not have been identified in our categorization. And these two categories have important implications in the South African educational context where large numbers of students are considered to have disadvantaged backgrounds.

In the following section we discuss some of the issues raised by our study and the response strategies we have identified.

Teacher-centred or student-centred?

One of the issues that struck us when examining the range of response strategies was a sharp division between teacher-centred and student-centred strategies. Strategies 1-3 are clearly teacher-centred and focus firmly on the content of physics rather than the more holistic goal of fostering disciplinary literacy. Thus, the first strategy we identified, *Not relevant*, may indeed be a logical response to the demands of teaching certain types of physics content; however, from a disciplinary literacy perspective, this response is clearly untenable as an overarching approach to the teaching of undergraduate physics. Similarly, given the overloaded nature of undergraduate physics curricula, an understandable (even essential) pragmatic response is highlighted in our second strategy: *Not my job*. Here again it is important to point out that it is the responsibility of the physics department to ensure that students develop sufficient representational competence during their undergraduate studies. Thus, from a purely professional point of view it is not defensible for an individual lecturer to argue that the development of a particular type of representational competence is someone else's job, without the department having decided *whose job* it is. Finally, whilst the third strategy: *Avoid problematic representations* may temporarily solve the problem of students' lack of representational competence, overuse of this strategy risks students never developing competence in that representation.

Strategies 4-6 are student-centred and focus on the fostering of disciplinary literacy, i.e. these strategies encourage students to develop their representational competence. Strategy 4

encourages translation between representations and thus follows the recommendations of a number of researchers in physics education (see the earlier section on representational competence in physics). Here, we suggest that such translation may allow students to discern the disciplinary affordances of a problematic representation i.e. the roles it may play in representing disciplinary knowledge (Fredlund et al., 2012). The fifth strategy, *Offer passive support* encourages students in the development of their own representational competence. This is clearly a useful approach and it is difficult to find any argument for why this strategy should not be universally employed. The final category, *Actively engage with the problem* may seem to be an ideal solution to the issue of student representational competence. Here, students are actively engaged in ways that optimally strengthen their construction of disciplinary knowledge. Since the seminal study of Hake (1998) such interactive engagement approaches have consistently been shown to be critical for physics learning outcomes (A recent example of work in this area is Deslauriers, Schelew, & Wieman, 2011). However, such interactive teaching of representational competence involves transforming the way that physics is typically taught taking both lecturers and students into new educational territory. This could be a daunting challenge, for example one of the physics lecturers in our study commented that, “*If I had to concentrate on language I would have terrible results*”.

Inter- and intra-faculty discussion

We suggest that in order to better meet the needs of undergraduate physics students, lecturers must reflect on the issue of representational competence and decide how it will be developed in the courses they teach. Here, we argue that knowledge about the range of available response strategies will allow physics lecturers to analyse the use of these strategies in their own practice and the practice of their peers. Further, we suggest that initiating discussions around the issue of student representational competence has the potential to improve the ways in which physics departments and individual lecturers meet the needs of their students. Such discussions could be both within individual physics departments and across a number of departments, with the goal of identifying best practice. This suggestion is echoed in one of the recommendations of the South African review of undergraduate physics that suggests that “physics communities of practice should be encouraged at the regional and national level.” (CHE-SAIP, 2013, p. 36). Our experiences whilst carrying out the interviews for this study lead us to further suggest that one way of structuring such discussions would be to use a disciplinary literacy discussion matrix similar to the one used for this study (see Appendix A).

The issue of ‘lazy students’

Another finding of the South African review of undergraduate physics is that many South African physics lecturers think their students are lazy (CHE-SAIP, 2013, pp. 16-17). Here we argue that although students may indeed appear to be lacking in work ethic, in many cases this may, in fact, prove to be a symptom of a lack of representational competence. Here, Northedge (2002, p. 256) suggests that university lecturers are often so deeply embedded in the discourse of their own discipline that they are “unaware that meanings they take for granted are simply not construable from outside the discourse”. From this perspective we argue that the possibility of laziness broached by one of the physics lecturers we interviewed can be seen in a different light.

*... they really struggle to interpret something that I would consider trivial ...
Happens often enough to think that they haven't been listening ... maybe
they're lazy.*

We suggest that what appears trivial to a representationally competent physics lecturer may be impossible to appropriately decipher for a student with weak representational competence. Here we found the following quote from one of the other lecturers to be particularly

enlightening:

Changing the representation ... mean[s] seeing the student in a new light in terms of their competence.

Language is always an issue

Finally, no article on representational competence in South Africa would be complete without a discussion of the issue of language. Although South Africa has 11 official languages, the majority of undergraduate physics teaching is carried out in English. All twenty of the physics lecturers we interviewed saw the issue of language competence as deeply problematic. This is a thorny issue and is, of course, intricately related to the history and politics of the country. Although beyond the scope of this article, questions of *which* language(s) representational competence should be developed in and *how* this may be achieved are clearly areas where an agreed approach needs to be developed. One potential problem found in the parallel Swedish studies is the insistence of physics lecturers that they are not language teachers (Airey, 2012). This sentiment is not something that is unique to physics, but has been found across a number of disciplines (Airey, 2011b). Here it has been argued that;

Until lecturers see their role as one of socialising students into the discourse of their discipline... [they] will continue to insist that they are not language teachers and that this should be a job for someone else.

(Airey, 2011b, p. 50)

Here again we suggest that inter- and intra-departmental discussions together with benchmarking of best practice may help.

Conclusion

In this article we have presented a qualitative study of South African physics lecturers' response strategies to a perceived lack of representational competence in their students. We identified six response strategies used by physics lecturers, ranging from the teacher-centred responses; 1. *Not relevant*, 2. *Relevant, but not my job*, 3. *Avoid problematic representations* to more the student-centred responses; 4. *Encourage translation to alternative representations*, 5. *Offer passive support*, 6. *Actively engage with the problem*.

Based on the differences in response strategies that we found across the twenty lecturers we interviewed and the five departments we visited, we have argued that inter- and intra-faculty discussions about disciplinary literacy goals have the distinct potential for contributing to the transformation of South African physics teaching. Here we suggest that the disciplinary literacy discussion matrix that we used to initiate dialogue in our interviews may also double as a useful starting point for such faculty discussions. At the same time, earlier when discussing response strategy 6, we pointed out that some of the lecturers that participated in our study were indeed involved in highly innovative transformation efforts. However, much more is needed:

Substantial improvements in undergraduate physics education have been made with existing knowledge and resources in a variety of contexts; encouraging and preserving these gains requires a symphony of efforts by many different participants, and improving on them requires continuing research and development.

(National Research Council, 2013, p.18)

We suggest that a broader appreciation of a range of possible response strategies to a lack of students' representational competence and how these strategies are put into practice will

facilitate physics lecturers efforts to transform the teaching of physics in ways that better match the needs of today's students.

Acknowledgements

We thank Cedric Linder for his comments on earlier drafts of this paper. Funding from the South African National Research Foundation and the Swedish Research Council is gratefully acknowledged.

Appendix A

Disciplinary Literacy Discussion Matrix

This matrix contains some of the many representations used in physics (down the left hand side). Given the overloaded nature of many physics degrees, please tick the boxes that you think should be emphasised for students to master **during an undergraduate physics degree course**. Please do this with respect to **where** students need this physics representational skill (for physics, for the workplace or for participation in society in general).

		Where for?		
		Physics	Job	Society
Graphs	interpret			
	use			
Tables	interpret			
	use			
Diagrams	interpret			
	use			
Mathematics	interpret			
	use			
→	interpret			
→	use			
→	interpret			
→	use			
Language	Reading			
	Writing			
	Listening			
	Speaking			
	Reading			
	Writing			
	Listening			
	Speaking			
	Reading			
	Writing			
	Listening			
	Speaking			

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