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TEACHING AND LEARNING SCIENCE

MULTI-THEORETIC APPROACHES TO UNDERSTANDING THE SCIENCE CLASSROOM

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Abstract: Multi-camera on-site video technology and post-lesson video stimulated interviews were used in a purposefully inclusive research design to generate a complex data set amenable to parallel analyses from several complementary theoretical perspectives. The symposium reports the results of parallel analyses employing positioning theory, systemic functional linguistics, distributed cognition and representational analysis of the same nine-lesson sequence in a single science classroom during the teaching of a single topic: States of Matter. Without contesting the coherence and value of a well-constructed mono-theoretic research study, the argument is made that all such studies present an inevitably partial account of a setting as complex as the science classroom: privileging some aspects and ignoring others. In this symposium, the first presentation examined the rationale for multi-theoretic research designs, highlighting the dangers of the circular amplification of those constructs pre-determined by the choice of theory and outlining the intended benefits of multi-theoretic designs that offer less partial accounts of classroom practice. The second and third presentations reported the results of analyses of the same lesson sequence on the topic "states of matter" using the analytical perspectives of positioning theory and systemic functional linguistics. The final presentation reported the comparative analysis of student learning of density over the same three lessons from distributed cognition and representational perspectives. The research design promoted a form of reciprocal interrogation, where the analyses provided insights into classroom practice and the comparison of the analyses facilitated the reflexive interrogation of the selected theories, while also optimally anticipating the subsequent synthesis of the interpretive accounts generated by each analysis of the same setting for the purpose of informing instructional advocacy.

Keywords: Classroom Research, Multi-theoretic Research Design, Science Education, Video-based Research

INTRODUCTION

As theories in the field of education continue to multiply and divide, it becomes increasingly urgent to determine how we can make use of this diversity to inform educational practice. The task of generating instructional advocacy from research findings that are grounded in different theoretical perspectives is a very challenging one, given the interdependency of theoretical choice and research findings. In carrying out classroom research, each theory affords particular analytical strategies, each focuses attention on specific aspects of the object or phenomenon under investigation but ignores other aspects. Inevitably, each should produce distinctive findings: the products of the particular analytical stance adopted. This theory-ladenness of observation has been recognized by researchers both from the field of philosophy of science and from social science (e.g. Guba & Lincoln, 1994; Kuhn, 1996), but only recently from the educational research community (e.g. Bikner-Ahsbahs & Prediger, 2006; Cobb, 2007). Tsaparlis (2001) argued that the use of various perspectives in science education, even potentially conflicting ones, could enrich our understanding of the teaching and learning of science. Clarke (2001) made a similar point in reporting a project in which a common data set drawn from eight science and mathematics lessons was subjected to analyses undertaken from ten different theoretical perspectives.

Since different research studies undertake data generation and analysis using different theories, the warrant that might be claimed for the consequent advocacy of any particular instructional action is contingent on the chosen theory/ies, among other considerations. In the research project that generated all the analyses reported in this symposium (Causal Connections in Science Classrooms – CCSC), multi-camera on-site video technology and post-lesson video stimulated interviews were used in a purposefully inclusive research design to generate a complex data source amenable to parallel analyses from several distinct theoretical perspectives (eg positioning theory, systemic functional linguistics, distributed cognition and representational analysis). The particular combination of theories was strategically constructed to provide complementarity of perspective such that each theory accorded emphasis to different features of classroom practice. Each theory, although being applied in the analysis of the same setting, offers distinctive insights reflective of the theory's foregrounded constructs.

This symposium reported the results of parallel analyses employing positioning theory, systemic functional linguistics, distributed cognition and representational analysis of the same nine-lesson sequence in a single science classroom during the teaching of a single topic. While each analysis is demonstrably valuable in itself, in combination, these results demonstrate the partiality of any single theory or theoretically-driven analysis in attempting to capture the complexity of the science classroom and the corresponding need for inclusive multi-theoretic research designs.

A LESS PARTIAL VISION: BENEFITS AND CHALLENGES IN A MULTI-THEORETIC STUDY OF ONE SCIENCE CLASSROOM[1]

A key aspiration of classroom research is the generation of empirically-grounded instructional advocacy. Since different research studies undertake data generation and analysis using different theories, the warrant that might be claimed for the consequent advocacy of any particular instructional action is contingent on the chosen theory/ies, among other considerations. In this symposium, rather than considering convergence or compatibility as the definitive result of the particular combination of theories, we focus on the compatibility of the interpretive accounts generated by their application to a common source of classroom data. In attempting to meet the challenge of providing evidence-based instructional advocacy, we address the question "under what conditions are the interpretive accounts compatible?" In this context, compatibility of the interpretive accounts would strengthen the authority of any recommendations for instructional practice arising from that research. We suggest that such compatibility must be considered as contingent on the events, objects or actions being analysed and on the specific question being addressed by the analysis. This contingent compatibility focuses our attention on the use of theories as interpretive tools.

Multi-camera on-site video technology and post-lesson video stimulated interviews were used to generate a complex data source amenable to parallel analyses from several complementary theoretical perspectives. This approach was intended to realize two very specific aims:

[1] This section summarises the first presentation by Clarke and Xu.

(i) Understand the setting: to maximize the sensitivity of the combined analyses to a wide range of classroom actions and learning outcomes, and
(ii) Understand the theory: through the combination of theoretical perspectives, examine the extent to which the results of analyses employing various theories and the theoretically-grounded explanations of these results are complementary, mutually informing, or, perhaps, incommensurable.

Science classrooms offer a rich educational environment, providing recordable instances of language use, a variety of classroom organizational groupings, varied instructional practices (demonstration, lecture, whole class discussion, and collaborative group work, both experimental and reflective), the utilization of a variety of artefacts (both physical and conceptual), the potential for ontological, epistemological, ethical and moral tensions to emerge, and, arguably, a highly diverse range of learning outcomes. It is this richness and complexity that offers the greatest potential for the interrogation of current theory and that also poses the greatest methodological challenge.

Data Source and Data Set

The focus of the parallel analyses reported in this symposium was a seventh grade science class of twenty-seven students (11 girls and 16 boys) aged between twelve and thirteen years. Data generation employed a four-camera approach (Teacher camera, two Student cameras, Whole Class camera), including onsite mixing of camera images into split-screen video records used to stimulate participant reconstructive accounts of classroom events in post-lesson student and teacher interviews (adapted from Clarke, 2006).

Figure 1a. Video material for student interview [Student camera: Teacher camera]

Figure 1b. Video material for teacher interview [Teacher camera: Whole class camera]

The video stimulus for a student interview consisted of a synchronized split-screen display of the video images generated by the teacher camera and the camera focused on that student and her nearby classmates (Figure 1a). The teacher viewed a similar composite video combining the teacher camera and whole class video images (Figure 1b)[2]. Additional data generated for each lesson consisted of copied or scanned written material (teacher planning material, student notes, textbook and worksheet pages, and test material) and observational notes made in the classroom by four researchers, three of whom were responsible for conducting the post-lesson interviews. A sequence of nine lessons was recorded, constituting the topic "States of Matter."

Formal data generation was preceded by two 'familiarization' lessons, in which all aspects of the data generation process were conducted for the dual purposes of familiarizing classroom participants with data generation procedures and familiarizing the researchers with the spatial configuration of the classroom and the typical interactional patterns and movements of the participants (camera positions relative to teacher and student locations are shown in Figure 2).

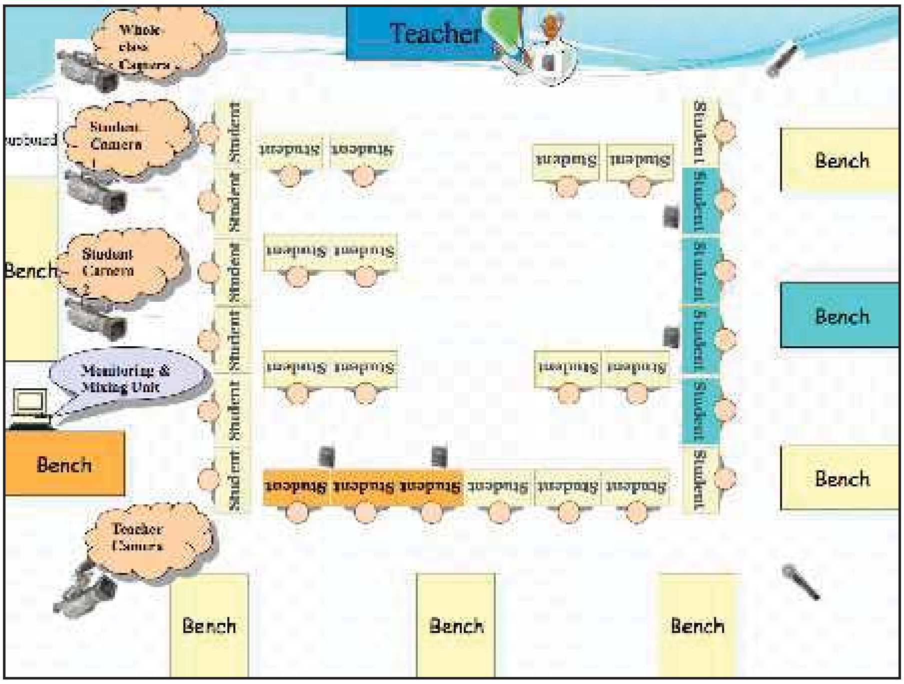

Figure 2. Classroom Layout showing camera configuration and radio microphone locations

We have an obligation as researchers to accept responsibility for the constructed nature of our data – and, of course, to document the process of data generation, identifying the points at which decisions were made regarding inclusion and exclusion. This is not always easy – particularly when the acts of exclusion are made for us by the technology, the method, or a theoretical frame that attends to some aspects of the setting and ignores others. In a multi-theoretic design such as the one employed in this project, we distinguish the "data source" constructed to anticipate and accommodate the parallel analyses from the data set reconstructed from that data source by each individual researcher for the purpose of a specific analysis.

Analysis and Synthesis in Multi-theoretic Research Designs

Each of the researchers participating in the CCSC project applied their own analytical perspective in order to select elements within the data source, thereby generating a distinct data set for each of the intended analyses. Each data set, so constructed, was then analysed using the same theoretical framework that guided the construction of the data set. In this

[2] For ethical reasons, actual images of the teacher and students cannot be shown. Images of students and teachers in both Figures 1a and 1b are simulated images developed for the purpose of illustrating the material used in the video-stimulated interviews.

respect, each analysis resembles any mono-theoretic research design in that the constructs privileged by the chosen theory were matched to data types and a research design constructed that employed methods suitable for the generation of the targeted data. Each independent analysis remained vulnerable to the same accusation of circularity or pre-determination that can be leveled at any mono-theoretic research design. Once available, however, the results of the parallel analyses can serve several purposes:

(i) By addressing different facets of the setting and thereby providing a richer, more complex, more multi-perspectival portrayal of actors and actions, situations and settings;

(ii) By offering differently-situated explanations for documented phenomena and differently-situated answers to common research questions;

(iii) By increasing the authority of claims, where findings from different analyses in relation to the same question or the same phenomenon were coincident;

(iv) By qualifying the nature of claims, where findings in relation to the same question or the same phenomenon were inconsistent or contradictory;

(v) By providing a critical perspective on the capacity of any particular theory to accommodate and/or explain particular phenomena, in comparison with other theories employed in analyses related to the same events in the same setting;

(vi) By facilitating the synthesis of the results of the parallel analyses for the purpose of informing instructional advocacy.

The derivation of all findings from the same data source through the application of all analytical approaches to the same setting greatly strengthened the project's capacity to realise these six purposes. In particular, multi-theoretic research designs integrate the activity of research synthesis into the research design as an essential element. The goals of research synthesis (Suri & Clarke, 2009) should not be limited to normative convergence on some form of best practice. In developing instructional advocacy arguments, it may be the identification of contingencies on any recommendations that offers greatest utility, by identifying combinations of context and action most likely to promote locally significant outcomes. Multi-theoretic research designs are intended to inform both theory and practice.

"I DON'T PAY ATTENTION THE WHOLE TIME": SCIENCE STUDENTS NEGOTIATING SOCIAL IDENTITIES AND PRACTICE[3]

This section reports findings from a study that sought to identify the circumstances under which participating students were positioned as agentic, and it supports an argument for a discursive approach to the study of agency.

Studies of student agency in science education have previously adopted ethnographic methodologies, using interviews and observations of particular students both in an out of their science classrooms in order to: a) determine the student's goals for the future, b) observe the student's actions that aligned with the student's goals and, c) determine the state of affairs both before and after student's actions in order to detect change related to the achievement of the student's goals. Based upon the ethnographic evidence, researchers have constructed students in research accounts as responsible for their actions and for bringing about changes.

Rather than assigning responsibility to students as described above, this study, in recognizing the constitutive force of language (Harré, 1992; Potter, 2001), sought to investigate science classroom discourse and identify moments in which students indexed responsibility to themselves. Of interest in the study was whether or not actions that the students indexed to

[3] This section summarises the second presentation by Arnold.

themselves as a responsible agent were taken up as legitimate in the classroom discourse. Therefore the response of others was taken into account in the discursive analysis of meaning making as the realization of classroom storylines and positionings.

Data Generation and Analysis

The research was conducted as an instrumental case (Stake, 2005) and the main source of data were the video recordings described earlier. The year-seven science class occurred at a large, multi-ethnic, suburban, government secondary school in Melbourne, taught by an experienced and well-regarded science teacher. As noted, the science lessons were filmed for the duration of an entire unit of work on 'The States of Matter'. The research took place in the last term of the year.

Focus students for this analysis were three female students, who had been very successful in science assessment tasks throughout the year, and who habitually worked together during small group tasks. The focus students wore microphones on lanyards during the lessons and participated in video-stimulated, post-lesson interviews on a rotating basis. These interviews, the researcher's observational notes, copies of lesson planning documentation and work produced by all students in the class provided supplementary information for clarifying meaning in the classroom discourse.

The audio tracks from all videos were transcribed. Conversations about science or whilst doing science in which the focus students participated were selected for the study. Phonological transcripts of these conversations were generated as data for the study.

A coding system, drawing upon the work of Muhlhaüsler and Harré (1990), was developed by the researcher for the purpose of identifying speech-action in which the focus students indexed responsibility to themselves. The coding system was based upon indexical features of our language that speakers can use to index their responsibility such as pronoun use, modality and tense, and together these grammatical features have been called by the resesarcher 'the grammar of agency'.

The meaning of the students' language use was analysed in the context of the conversational episode in which the students used the grammar of agency. Meaning was analysed using discourse analysis in social psychology (Harré & Langenhove, 1999a; Wood & Kroger, 2000), and in terms of the storylines and positionings that were realized jointly by the participants in the conversation. Nine of these conversational episodes were used to communicate the findings of the study because they exemplified variability in the way the girls indexed responsibility to themselves and were representative of the way in which the girls' actions were taken up by others in the classroom discourse.

Results

This sample analysis focuses on one of the focus student's (Tasha's) use of the 'grammar of agency' to position herself and her friends as responsible for actively seeking the scientific knowledge. Tasha had identified the knowledge she lacked and pursued the knowledge by asking her friends, *"What is the Particle Theory?".* However, her friend, Kesar's response was, "You're seri(h)iosly asking me that?". The social force of Kesar's utterance was Kesar's repositioning as not responsible for knowledge seeking. Subsequent to Kesar's repositioning, Tasha published the biographical "small story" (Bamberg, 2004): *"I don't pay attention the whole time… seriously! I haven't heard about the Archimedes in the bathtub thing"*, which had the function in the conversation of repositioning Tasha in alignment with her friend. The biographical story was face-saving for Tasha and the dominant storyline in their conversation became, 'Students' as responsible for passively receiving scientific knowledge'. The analysis of the function of Tasha's biographical story illustrates the importance of the distinction made by discursive psychologists (Harré & Langenhove, 1999b) between the storying of oneself in autobiography and the realisation of one's position in an ongoing conversational storyline for the development of one's social identity and the realisation of social practices.

Discussion

The girls' actions can be understood in terms of a conversational background in which their social identities as members of a student group who were not expected to know the particle theory were realised. Rather than expressing her own lack of knowledge of the particle theory, Tasha's statements *"I don't pay attention the whole time… seriously! I haven't heard about the Archimedes in the bathtub thing"* were practically orientated towards maintaining solidarity with this student group.

In this way, the collectively realised classroom practices constrained Tasha's development of a social identity as an active seeker of knowledge. Her social identity as a knowledge-seeker was not taken up as viable within the girls' small group and was not published beyond their small group, limiting her opportunity for being positioned as agentic. The findings of the study suggest that reflexive attention to student inquiry and collaboration could enhance opportunities for students to be positioned as agentic. This is supported by Mercer and his colleagues (eg Mercer, Warwick, Kershner, & Kleine Staarman, 2010), who found that the teacher's "vicarious presence" was an important factor in determining the degree to which students engaged in collaborative, dialogic activity.

A goal of this study was the development of a "workable" definition of student agency as a form of discursive practice in which students are positioned as responsible agents. The focus of this study was a discursive psychological account of the variability in agentic positioning by three academically successful science students. By focussing on agency as a discursive practice it was possible to show that the participating students' opportunities for developing social identities as responsible agents within science was constrained by their joint action directed towards the passive reception of scientific knowledge. This illustrates the potential utility of a discursive approach in studying agency and supporting reform efforts in science education directed towards student inquiry and dialogic activity.

STUDENTS' LANGUAGE USE AND ITS RELATION TO THE REQUIREMENTS OF SCIENCE INSTRUCTIONAL TASKS[4]

This linguistic analysis was motivated by an interest in understanding the challenges that students face when appropriating and employing the language of school science in the classroom context. There are at least three assumptions underlying this study. The first and foremost assumption is that learning language of school science is constitutive of learning science (e.g., Lemke, 1990). This assumption provides the main impetus of this study. The second assumption is that learning in the science classroom involves learning its social practices, of which responding to instructional tasks constitutes an important aspect. A third assumption is that the use of language is situated and functional, which implies that language use can vary with the requirements of a task. This assumption is in line with the use of Systemic Functional Linguistics (SFL) framework as the analytical lens (Halliday, 1994).

In this study, each written explanation from students was first examined at both content and lexicogrammatical (LG) level. Subsequent to both content and LG analysis, we compared and contrasted a set of explanations found in students' practical reports with another set of explanations found in their test papers. This method of comparison involved the identification

[4] This section summarises the report authored by Seah, Clarke & Hart

of qualitative differences in language use between the two sets of explanation that might be related to the specific requirements of each task.

The analysis was guided by the following research questions:

1. What are the similarities and differences in the students' use of LG resources between the two tasks?
2. What are the similarities and differences in the requirements between the two tasks?
3. What are the possible connections between the students' language use and the requirements of the tasks?

Data Generation

Among the data generated, the most relevant for the present study were two sets of written explanations completed by students. Below is a description of the source of these explanations:

I. Practical report on expansion

Mr. Gardiner distributed a practical worksheet, which described three activities:

Activity A: Students were required to pass a metal ball through a ring before and after heating (an example of expansion of a solid).

Activity B: Students were asked to fill a flask with coloured water and fit a stopper with a piece of glass tubing through it, before putting the flask in a container of hot water for a few minutes and then subsequently in a container of cold water (an example of expansion of a liquid).

Activity C: This involved heating with a Bunsen flame an empty conical flask, the mouth of which was covered with a deflated balloon (an example of expansion of a gas). Unlike the two activities above that were performed by the students themselves, this activity was demonstrated by the teacher.

For each activity, the students were told to record in their practical book: (i) their prediction of what they thought would happen; (ii) their observation of what happened; and (iii) their explanation for what happened.

II. Test item on expansion

A week after the practical task on expansion, the students sat for a test on the topic "States of Matter", which included a test item on expansion (see Figure 3). As with the practical task, this test item required students to provide an explanation. Data from the lesson videos and interview videos constituted supplementary data useful for understanding the context and for triangulating the meanings ascribed to the written language.

What is expansion? Explain using **clear, labelled diagrams** in the spaces on your answer sheet.

23 a)

Figure 3: Test item on 'What is expansion?'

Analysis

1. Content analysis I: Classifying all students' explanations according to their content using different coding categories referred to as "explanatory foci". Altogether, three explanatory foci - each addressing a specific aspect of expansion – were identified from among the two sets of explanation:

- Macro reference: represented expansion at a macro-level by describing the perceptible aspects of the phenomenon;
- Submicro reference: represented expansion at the submicro-level by interpreting the phenomenon in terms of the particle model of matter;
- Causal reference: invoked a cause (e.g., an external agent or a condition) that brought about the expansion.

2. LG analysis using SFL: The following analytical categories from the SFL perspective were utilised to classify the LG resources employed by the students into linguistic classes:

- *Process*: is typically expressed by a verb or a verbal group and is associated with a small set of *Participants* such as *Medium*, *Agent* and *Range*
- *Medium*: is typically expressed by a noun or a nominal group and is the indispensable *Participant* without which the *Process* would not 'exist'; both the *Process* and the *Medium* constitute the core of the clause, which is the unit of the LG analysis
- *Agent*: is also typically expressed by a noun or a nominal group and is 'the entity that does or acts; the cause or instigator of a process' (Lemke, 1990, p. 222)
- *Range*: can be expressed by a noun or an adverb and refers to 'the limits, extent, or nature of what the process does' (Lemke, 1990, p. 222)
- *Circumstance*: is prepositional phrase, adverbial group, or nominal group that express the circumstances (e.g., of reason, of condition, of location, of means etc.) associated with the *Process* or the *Participants*

These linguistic classes enabled us to differentiate the function that LG resources served to realise scientific meaning. LG analysis highlighted the similarities and differences in the use of LG resources among the students' explanations, facilitating the next phase of analysis.

3. Content analysis II: This phase involved identifying the diversity of meanings realised within each explanatory focus.

Findings

Several ways in which the task requirements might have shaped students' use of LG resources were identified. Specifically, the similarities between the tasks (e.g., the focus on expansion and the requirement to "explain") might have contributed in part to the following similarities between the two sets of explanations: the presence of the same three explanatory foci; the same explanatory focus being associated with a common set of LG resources and addressing the same aspect of expansion; and the same diversity in the types of explanation found among the responses for each task. On the other hand, the differences in nature between the tasks (e.g., specific instance of expansion versus expansion in general; no request to use diagrams versus with such a request) might have contributed to differences between the two sets of explanations that included: the presence/absence of purely causal type of explanation; the diversity of instances of expansion; the presence/absence of certain scientific meanings; the frequency of LG resources employed to link the various explanatory foci together; and the frequency of "it" being employed indiscriminately.

From the findings, we can postulate several mechanisms through which the students' language use might have been shaped by the requirements of a task. In the case of the practical activities, the task determined the observations expected and these in turn shaped what and how particular LG resources were employed. The way students employed LG resources could also be mediated by the students' interpretation of the requirements of the task and their awareness of the differing requirements of the various tasks. The role of the task itself in shaping students' use of LG resources suggests that learning the specific requirements of science tasks is part and parcel of 'the ways of knowing and practices of school science' (Driver, et al., 1994, p. 11) that students need to be 'enculturated' to successfully integrate into the community of the science classroom. For instance, the diversity of the students' explanations in terms of types in both sets of explanations suggests that some students were not clear about what it meant to explain in the context of a science task. As students may have varying interpretations of what a task asks of them, teachers may need to discuss and explicitly unpack the requirements. This study shows that by exploring the possible ways in which a task can shape students' use of LG resources, we can expand our understanding of the challenges that students face when they are required to employ the language of school science in the classroom context. Finally, an understanding of how the requirements of tasks could affect students' responses may also assist in lesson planning by suggesting what kinds of task could be suitable for different stages of instruction.

DISTRIBUTED COGNITION VS. REPRESENTATIONAL PERSPECTIVES ON A CLASSROOM SEQUENCE ABOUT MATTER[5]

Comparison is made between two distinct analyses of the same sequence of science lessons on the topic of matter, involving macroscopic and particle ideas, the first using distributed cognition and the second a representational, semiotic perspective. Through such a comparison, an attempt is made to explicate some key similarities and differences of the two theoretical lenses that could afford a better understanding of the affordances of each theory and how each of them could contribute to advancing our thinking about science teaching and learning in classrooms.

Data Generation and Analysis

The lessons analyzed formed part of a three-lesson sequence on the topic of states of matter, but with a specific focus on the concept of density. The concept of density was only addressed in Lesson 2 and Lesson 3. Lesson 1 provided some background information regarding what the students knew about the three states of matter and the particulate nature of matter, which had some influence on student interpretation of density in the two lessons that followed.

Distributed Cognition

Key to the analysis is the interplay between student prior knowledge, the resources made available in the classroom (including physical, conceptual, and symbolic artefacts), and processes (for example, classroom discussion, teacher demonstration). The key question in the DCog analysis is how the interplay between the three components contributes to changes in patterns of interaction (such as ways of seeing, talking and thinking). The analysis of learning outcomes focused on the work of four male students, who worked together throughout the sequence. It is useful to outline briefly the key instructional acts undertaken during the three lessons in question:

1. An official definition was introduced by the teacher, drawing student attention to the formula on a worksheet. In the formula, density takes the form of mass being divided by volume;

2. To illustrate the meaning of density, the teacher presented two blocks of metal to the class: lead and aluminum. Both blocks were cubic in shape and of the same volume (see Figure 4).

[5] This section summarises the presentation by Xu and Tytler

As the teacher explained in the post-lesson interview, the demonstration of the two blocks was intended to show that the size of an object does not matter but substance matters. The two metal blocks served as an important cognitive artefact for student sense making of the density concept. Cognitive artefacts, in DCog terms, are man-made physical objects for the purpose of aiding, enhancing, or improving cognition (Hutchins, 1995). In this case, the two blocks provided a physical embodiment of the concept of density;

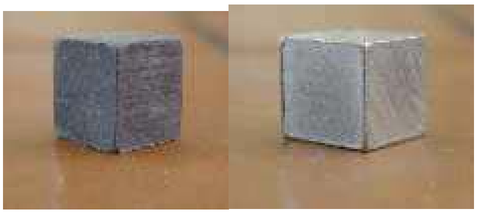

Figure 4. The two metal blocks (lead and aluminum)

3. A third event in the density lessons was the practical activity on measuring the density of a candle and a marble. According to the post-lesson teacher interview, the practical activity was intended to allow students "to get a physical feel for a concept", and "to introduce the term density as mass divided by volume" [0:18:10, L02-INT_T]. In this practical activity, one of the focal artefacts was the worksheet on measuring the density of two objects: a candle and a marble, which set out the aim, materials, methods, and questions for discussion. Like other cognitive artefacts (e.g. the two metal blocks), the practical worksheet was created with an intention to influence the practice of the user in particular ways. This worksheet prescribes the procedures for measuring the density of a candle and a marble, and it serves two main functions: as an instructional device that guides student action and as an inscription device that documents experimental results.

The DCog analysis highlights the important role of different artefacts in mediating student participation in collective activities and student sense making of science. The employment of physical artefacts, such as the two metal blocks, served as a common referent for anchoring the classroom discussion on density. The presence of the two metal blocks also enabled the students to interact with the abstract scientific concept in a concrete way by directing their attention to the features of the two blocks that were made relevant in the classroom interactions. In particular, it gave emphasis to the mass and the number of particles in determining the density of an object, which were later appropriated by many students to be the key determining factors for the density of a candle and a marble. On the other hand, the presence of the two blocks blinded the interlocutors (the teacher and the students) to a potential mismatch in their focus of attention: the density of an object and the density of a substance, since they assumed that they were referring to the same thing. Despite the teacher's intention to show that density depends on the substance of an object, both the teacher demonstration and the student practical work drew student attention to the specific properties of an object, such as mass and volume. It can be argued that underlying the difficulties in understanding the macroscopic and microscopic relationship is the lack of emphasis on the notion of "substance", which could potentially provide a conceptual bridge between the macroscopic and the microscopic properties (see Xu & Clarke, in press, for a more complete analysis of the two lessons on density).

A Representational Perspective

Recent work has focused on the need for students to be guided to construct and negotiate representations as part of learning to reason with these epistemic tools (Hubber, Tytler & Haslam, 2010; Waldrip, Prain & Carolan, 2010). Pragmatist perspectives (Peirce, 1931-58) have been used to interpret student learning and reasoning in terms of the triadic relationship between meaning making, multiple representations and their real world referents. This research analysed the learning environment in terms of challenges and supports it afforded students to coordinate the multiple representations involved in constructing explanations of density and the properties of matter.

The teacher's stated main aim in these lessons was to establish the macroscopic, mathematical definition of density through the formula D=M/V. From the perspective of Peirce's triadic model of meaning making, this involves linking the representation (the formula) with the real world referent in a 'weaving' process by which the capacity of the representation to make sense of phenomena is evaluated and its meaning refined through use.

Analysis of the video record of the three lessons related to density demonstrated the multiple representations that were introduced by the teacher to establish the meaning of the term. These included mathematical formulation of the mass-volume relationship, tabular representation of mass, volume and density associated with an experiment, role play of particles to establish differences between solids, liquids and gases, verbal and written explications, as well as the use of physical artefacts such as the aluminium and lead 'density blocks'. The analysis has illustrated the complex coordination of a series of partial and selective representations necessary to achieve a flexible understanding of density, and the demands this coordination places on teachers to support students in apprehending the features and purposes of the representations, and in making connections between them. Analysis of the representations, demonstrated:

- The need to explicitly support students in understanding the form and function of the various representations and the cost in this sequence of presenting each representation without adequate framing and negotiation;
- The need to frame student challenge activities to allow them to adequately explore and evaluate representations as making sense of perceptual phenomena, and the cost of having scripted, limited opportunity to do this. Thus, for instance, the mathematical expression for density was not utilized by students in a way that demonstrated its capacity to make sense of patterns of mass, volume and flotation in a range of materials;
- The need to acknowledge the selective nature of representations and the need to support students to coordinate a range of representations across different modes, rather than have them introduced and discussed largely independently and with limited reference to each other.

The representational analysis demonstrates the complexity of supporting student understanding of the density concept, and provides an interpretation of the difficulties recognized in the literature (confusion between substance and object, of difficulty of dealing with ratio, and of difficulty with particle ideas) as being fundamentally representational in nature. The teacher in this sequence introduced a range of potentially powerful activities including particle role-play, practical experiences, a tactile demonstration and extended discussion. However, perhaps due to time constraints, and because of the way the open classroom discussion was diverted by students' unanticipated exploration of particle ideas, there were limited opportunities for consideration of the form and function of each representation of density or of the way they interrelated. From a representational perspective this imposed severe limitations on the achievement of a flexible understanding of density.

Discussion of the comparison of Distributed Cognition and Representational Analyses

The first point to make about the two theoretical perspectives is that they focus on different units of analysis. DCog theory was developed to explain the way knowledge and learning are distributed within and across systems, in this case the classroom system, whereas the representational perspective focuses more centrally on the nature of individual meaning making, leading to consideration of how representational resources are opened up in the public space to support this. The DCog perspective highlights the mismatch in the focus of attention between the teacher and the students, and the limited connection between the macroscopic and microscopic views of density. The representational perspective highlights the mismatch as a lack of explication and negotiation of the multiple representations through which density is understood. But each perspective has its own limitations. Distributed cognition arose from studies of workplace settings, and therefore lacks a pedagogical view about how things should be or could be in the classroom. The representational perspective, on the other hand, has a strong literacy focus, but is less well developed to analyze situations involving many physical resources, such as science practical work. The two theoretical perspectives together provide a richer interpretation of the classroom practice studied.

Both theories come from a socio-cultural perspective that acknowledges the role of a variety of artefacts including language and inscriptions, in mediating learning, or generating meaning. The theories differ however in the emphasis they place of aspects of the classroom processes. Thus, while the representational perspective properly includes physical artefacts as having representational value, its focus has tended to be on multimodal inscriptions of various kinds as part of the argument for a literacy based perspective on learning and knowing. The aluminium and lead density blocks figure significantly in both analyses, and both theories concern themselves with their meaning in use, but their role is perhaps more naturally emphasized within the DCog perspective. This is because of the historical emphasis of DCog on how physical tools and other kinds of artefacts can transform the nature of the tasks to be performed by people.

The two theories allow distinct perspectives on teaching and learning, together providing a richer interpretation of the sequence than either on its own. The two analyses uncovered different perspectives on the relationship between physical and conceptual artefacts mediating learning, and on the nature of student learning and understanding. It is argued that such an analysis, utilizing a common data set, allows us to better understand the particular affordances of each theory and how constructs such as 'artefact', 'representation', 'conceptual', or 'coordination' sit in different relations to each other within the two theories.

CONCLUDING REMARKS[6]

In this symposium, we provided a demonstration that the theoretical choice one makes not only constrains the particular type of questions that one can ask and the particular type of phenomena that one can investigate, but also orients one towards providing a particular line of explanation for the question under investigation. We have illustrated this with parallel analyses of the same classroom events. These parallel analyses illustrate the capacity of each theory to address the connection between learning and instruction, to accommodate and to predict the likely benefits of particular instructional approaches.

The explicit comparison of analyses undertaken using Distributed Cognition and Representational perspectives has implications for the CCSC project's goal of facilitating the interrogation of theory (as well as the illumination of setting and process). Specifically, the two theoretical perspectives (Distributed Cognition and Representational Analysis) occupy the same cognitive territory, and to a large extent have overlapping histories in their adherence to material interpretations of knowledge, and to notions of mediation. Unlike analysis involving positioning theory for instance, or systemic functional linguistics, which focus respectively on student agency and lexicogrammatical resources, DCog and

[6] These concluding remarks incorporate comments from the symposium's discussant: Vaughan Prain.

representational perspectives both purport to deal with the way knowledge is constructed and enacted. These similarities throw up more sharply the relationship between the theoretical constructs, and the different foci, of the two theories.

The interpretations offered by the two theories appear in large part to be compatible, but their foci of attention of attention are different. For DCog, the distribution is across artefacts and people in a classroom, while Representational perspectives look at the way individual knowledge requires coordination of (is distributed across) multi-modal representational resources which are opened up and negotiated in the public space of the classroom. The two theories thus take a similar stance towards learning and knowledge, but from the perspective of the system, and the individual, respectively. The analyses informed by Positioning Theory and Systemic Functional Linguistics can also be distinguished by their foci of attention. Yet, the social realization of student agency and the use by those same students of lexicogrammatical resources are connected by the recognition that both activities are mutually constitutive of the students' engagement with the learning of science.

The interdependence of theory and analytical results has significant implications for our understanding of the role of theory in researching science classrooms. It is only through comparing the parallel analyses of data generated from a common data source that the core similarities and differences between theoretical lenses can be made explicit. In this way, new knowledge could be established with regard to how the various theories could possibly be compared or combined to inform research and practice. It is not our intention to challenge the value of research studies conducted from a single theoretical perspective. In fact, each presentation reports precisely such mono-theoretical accounts. The challenge is to integrate theories of the learning task, theories of learner attributes and theories of acquisition and participation processes in the cause of building theory or theory networks to inform classroom practice.

Our goal has been to explore some of the issues associated with the implementation of a multi-theoretic research design. If we are to progress as a community, we must develop methods by which we can contrast, connect and learn from our extensive and continuing research efforts. Multi-theoretic research designs attempt to exploit the value of analysing the same setting(s) from a variety of theoretical perspectives. We would like to suggest that the benefits include: increased insights, less partial portrayal, and the capacity to interrogate and refine both setting(s) and theories.

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