CHARACTERISING SCHOOL STUDENT DISCOURSE WHEN ENGAGED WITH CONTEMPORARY BIOLOGICAL RESEARCH

Ralph Levinson[1]*, Haira Gandolfi[2], Irene Hadjicosti[3], Paul Davies[4], Constantinos Korfiatis[5] and Stephen Price[6]
University College London[1,2,4,6] , University of Cyprus[3,5],
r.levinson@ucl.ac.uk[1]

This study involved four groups of six students, aged 16-17, discussing a contemporary biomedical research problem. Drawing on Chinn and Malhotra's (2002) criteria for authentic scientific research we analyze those patterns of talk and use of knowledge which lead to outcomes reflecting authentic science practice. Adapting a coding scheme from primary school science discussions in constructing knowledge we show that fruitful discourse has the following features: authoritative scaffolding encouraging elaboration, explanation and reactualization of school knowledge; willingness of participants to problematize suggestions; collaborative elaboration of ideas sufficient to stimulate new research questions. We advocate the profitability of such research problems to move beyond the constraints of the curriculum to deepen student understanding of research science.

BACKGROUND

In discussing authenticity, Kapon, Laherto and Levrini (2018) refer to a need to "awaken . . . the scientific spirit" and the practice of scientists. Tensions exist, however, from prescription of content at one end to creativity at the other. For example, the tension between "content fidelity" (Kapon et al., 2018) – established knowledge and procedures, contrasted with personal relevance to students as generators of their own knowledge. Another problem, pertinent to the project we discuss below, is that of "language and discursive norms" (Kapon et al., 2018); for example, school students are often assessed on knowledge they have acquired as individuals whereas research discourse reflects collaboration, communicative acts of normative meaning (Derry, 2016). 'Significance' exposes another tension: that between the topics and methods of professional science and solving personal or community-relevant problems.

Chinn and Malhotra (2002) identified significant differences in cognitive and epistemic perspectives between school science inquiry and authentic science research which reflects aspects of authenticity discussed above. These differences, based on Chinn and Malhotra's analysis are listed in Table 1.

Process	Research science	School science
Research questions	Generate or adapt own research question	Research questions provided
Variables	Select variables to investigate out of many possibilities	Investigate and report on prescribed variables
Planning procedures	Invent complex procedures to address questions of interest	Follow simple directions or devise simple procedures with predetermined variables
Controlling variables	Difficult to decide what controls should be or how they should be set up.	Told what variables to control
Finding flaws	Constantly question their own or others results, or artifacts and experimental flaws.	Flaws in experiment rarely salient or assume extrinsic flaws such as doing experiment incorrectly.
Indirect reasoning	Observations related to research questions by chains of inference	Observations directly related to research questions
Generalisations	Need to judge whether to generalise from the experimental situation to other situations.	Only generalise to similar situations.
Types of reasoning	Employ multiple forms of argument	Simple contrastive, inductive or deductive reasoning
Level of theory	Construct theories postulating relevant mechanisms	Either uncover empirical regularities or illustrate theoretical mechanisms

Table 1: Differences between scientific research and school science inquiry

Our research was directed at exploring how students might use their school knowledge when engaging with an open research problem and the types of interactions that might facilitate deeper understanding. Findings that emerge from this research will inform science teaching particularly for those students transitioning from school to university, and also for undergraduate science teaching.

While most investigations on students learning authentic practice has focused on laboratory-based activities, our intention was to draw on the ‘elaboration of ideas’ behind mechanisms (Abrahams & Millar, 2008), removing the possible distraction of manipulating sophisticated instruments in a laboratory environment.

THEORETICAL FRAMING

In this project we were interested in how knowledge underpinning scientific research, as depicted by Chinn and Malhotra (2002), is constructed through discussion, and what kinds of discursive features enable the production and use of such knowledge. For example, what are the social moves in a discussion which enhance or inhibit productive reasoning about research? What are the differences between addressing a problem within the constraints of the curriculum and one which presents an entirely new arena of thinking? What for school students would constitute acceptable evidence and what means would they use for validating that knowledge? Students were aiming to provide explanations for a biological phenomenon which was new to them. To provide plausible accounts they had both to draw on their pooled prior knowledge and construct new meanings: they were asked to draw on different types of knowledge – academic school knowledge, knowledge of doing experiments, experiential and situated knowledge – to explain why groups of cells in the embryonic spinal cord independently segregate (see Methods for a fuller account of the problem). Gaps arise between what is intelligible and ‘stands fast’ for the students (Wickman & Ostman, 2002). Discursive encounters between participants, the scientist and representations of the process help to construe new meanings. In this study we view knowledge from a pragmatic perspective in which it is seen as action, something that is done rather than located inside a subject’s head. Meaning making takes place where participants in a discussion create connections between prior knowledge and the situation at hand, i.e. ‘reactualizing’ their knowledge.

The relevance of Wickman and Ostman’s paper to our research is that it goes beyond the situational aspects of learning to explain how, on a discursive level, meaning changes in the light of new experiences. Through a pragmatic approach they view learning as a social construction acknowledging the physical world as encountered by with cognitively and emotionally acting and interacting individuals. Our focus is on how prior knowledge changes when students are confronted with new and complex phenomena to make sense of in discussion. Such an awareness of change putatively leads to problematising enaction of scientific concepts and, through dialogic interaction, to building new knowledge where gaps previously existed. Encounters between participants and the ‘texts’ influence meaning and involve prior knowledge and experiences.

Our research questions are: 1. To what extent does engagement in authentic inquiry enable school students to exhibit salient features of research science? 2. What discursive features enable fruitful moves towards authentic inquiry? 3. How do students use their extant knowledge to address a novel and complex situation in scientific research?

METHOD

We invited four groups of students from three different schools to address a research question which the developmental biologist has been working on for the past 20 years, namely to account as far as they could for the separation of cells through the process of differentiation and specialization in the developing spinal cord. The discussions took place in a room at the university. Six students were apportioned to each group; students in each group were from the same school and were familiar with each other. Three of the groups came from schools in socially disadvantaged areas and were gender-mixed. Participation was entirely voluntary and students were sent a letter explaining the research and opt-in and opt-out options.

The research took place over two separate days and all the discussions were recorded and transcribed. Notes were taken in situ to describe any relevant gestures or writing to complement the transcriptions. Initially, the problem was framed as being one found in all tissues and all animal species and schematized in a figure showing two different cell-types represented by two sets of differently colored spheres.

The spheres were initially shown as randomly intermingled with representation of time being shown as an arrow whereupon the two colored spheres segregate and cluster into two distinct groupings. The pupils were then asked to draw upon their current knowledge across all subject areas to hypothesize how the two different cell-types could segregate and cluster.

The discussion about these slides took the following format. - The scientist presented the problem orally to the students together with a simple model of differently coloured cells asking them to explain how they could account for their separation. They were encouraged to suggest experiments they might carry out to support their explanations together with evidence they would be looking for; they could ask the scientist any question they deemed necessary at any point; a volunteer from the group was to summarize their discussions once they had exhausted explanations, and before the next stage of the process was presented to them. Altogether the slides were presented in a sequence. It is the first two that are relevant to the discussions below. The duration of the discussions was between 70 minutes and 94 minutes.

Coding for the analysis was drawn from Hogan, Nastasi and Pressley (1999) where groups of students, albeit primary school students and under closer teacher guidance, are trying to make sense of incomplete scientific ideas. Our students were similarly working through dialogue towards an end of trying to either establish consensus or at least rational grounds for disagreement around new scientific ideas they were trying to make sense of. We have modified these micro-codes from Hogan, Nastasi & Pressley (1999) to take account of the particular context of this discussion (Table 2).

The dialogic interactions were organized into episodes. An episode comprises an opening statement on a topic which might be in the form of a question, assertion, conjecture, prediction, summary or focus towards a task. Such a statement leads to a response by at least one other person in the group or the research scientist (RS) if he had been called upon, and the focus on the topic then continues for at least one more statement.

The dialogue was then organised into codable units. Four of the researchers shared their codes. Differences between specific codes were negotiated and a new scheme drawn up. This was done three times until there was complete inter-rater agreement. Where conceptual knowledge drawn from the school curriculum was used or mentioned in a sequence this was also noted as were any aspects of research science derived from Chinn and Malhotra's analysis in table 1.

Statement type	**Sub-statement (code)**	**Description**
Initiates	Initiates episode (In-Ep) Initiates idea (In-I) Initiates partial idea (In-PI)	Statement which generates episode. This might be incomplete conceptually but is sufficiently substantive to invite follow up. Statement which specifically directs attention to a possible mechanism Statement which is vague but can be built on towards a mechanism or model.
Elaborates	Self (El-S) Other (El-O)	Participant builds on a previous statement they have made Participant builds on previous statement made by another participant
Clarifies	Self (Cl-S) Other (Cl-O)	Makes clear previous statement participant has made without adding further concepts or ideas. Clarifies statement of another participant without adding further concepts or ideas

Statement type	Sub-statement (code)	Description
Explains	(Ex)	Gives a reason for concept or idea.
Gives evidence	(Ev)	Produces putative evidence for an idea or concept which can be tested. Often in the form of a prediction.
Problematises	(Pb)	Questions the validity of a claim
Reviews	(Rev)	Summarises or reviews what has been said
Question	(Q)	Any statement designed to elicit a response
Response	Neutral response (R-N) Positive evaluation (R+)	Acknowledgement of previous statement of participant without any kind of evaluation Acknowledgement with positive value comment of previous statement
Subject knowledge	(SK)	Where participant draws on conceptual scientific knowledge, usually from school curriculum either explicitly stated or inferred
Metacognitive	M	Participant explains how they are thinking

Table 2: Coding structure

RESULTS

We have drawn on three episodes to illustrate discursive moves which reflect authentic science inquiry. As a significant qualification, these three were the only substantive exchanges which we could depict as episodes. Nonetheless, we argue they comprise dialogic features where collaboration enables students to demonstrate fruitful practice in attempting to close a cognitive gap through the use of knowledge. For reasons of space we only focus on more salient exchanges.

Episode A

For the first seven minutes of the discussion students from Group 1 have been discussing what makes the two types of cells (modeled as orange and green) separate with little progress. In the initial sequences, one of the students, Muna, offers vague suggestions with the Research Scientist (RS) prompting her to elaborate her ideas.

Muna: Would you have to see, because it happens all over the body, so would you have to see any common factors that's linking all of the groupings together? (Q; In-PI)

RS: That's really good, yes. (R+) . . . how would those common things work do you think? (Q)

Muna: . . . not quite sure (M), things like pH levels or iron levels or whatever's going on you can link together and what could attract cells (In-Id; SK).

RS: OK (RN).

At this point, another student in the group, Rabia, makes her first contribution drawing on her school knowledge, offering a specific explanation of cell signalling.

Rabia : So like cell signalling happens with glycoproteins (SK), so maybe then to find signs of glycoproteins in an orange cell or a green cell could help differentiate them (Ex; Ev).

RS : OK (RN). . . .So what is the model that you are making? (Q) How does that make [the cells] separate? (Q)

Rabia : . . . things might like attach to the glycoproteins (Ex) because I'm just like linking back to things that we've done in school, with like antibodies and stuff (SK).

RS : Yeah (RN).

Rabia : So they are specific to certain antigens, so if an antigen, antigens such as proteins, so if they are not found on the green cell then the thing in the body wouldn't be able to attach to the green cell to be able to bring it over to a different area (SK; Ex).

RS : OK (RN).

Rabia : So if there was a mechanism that, like, attached to one of the proteins on the membrane of the orange cell but it wouldn't be able to attach to the green cell, then eventually over time all of the orange cells would end up in one place being attached to those proteins. (Ex; Ev).

In relation to Table 1 two distinct features of authentic research science have been demonstrated: (i) constructing a theory postulating mechanisms; i.e. molecular bodies attached to proteins in the cell membrane, and (ii) Drawing on school science knowledge about antibody-antigen mechanisms to formulate an explanatory model.

Episode B

Episode B follows shortly after Episode A where the group now considers the evidence for Rabia's model. Muna again initiates a tentative suggestion of testing for proteins in the membrane but this suggestion is challenged because they do not know which protein to test for. Don then proposes a control experiment to check if proteins are the material cause of cell separation.

Don : What about if we denature the proteins . . . (P-Id; SK). . . so we heat up the cells and let the proteins denature but the cells don't get destroyed, and then we see, if they still split… (Ev).

Muna : Yeah, that would be good (R+)

Nita : But would it be possible to denature the protein without affecting how the cell works? (Pb)

We have extracted here the central problem identified by Nita that denaturing the protein influences more than one function hence control experiments in scientific research are more complex than those experienced in school science.

In this episode in relation to Table 1, students: find flaws in their experimental design; employ rebuttals in problematising; construct knowledge in groups (they have been able to explain collaboratively why the gap between their explanation and outcome is so problematic.

Episode C

Episode C was taken from the discussions of group 3 just after RS has introduced the second slide (Figure 1B).

Orla	:	That immediately made me think about electrolysis and how they move to one side (In-Ep; SK), so maybe it is kind of like the cells signalling how they are, like it's within them to go and move to the other side (Ex), so then the orange wouldn't have been separated, they'd have just been left behind (Ev).
Group	:	OK (RN)
Carol	:	So it's to do with the green cells (Cl-O) rather than an interaction between the two types of cells. (El-O)
Group	:	Yeah.(RN)

After this every member of the group offers ideas, some of which are refuted, resulting in Katie summarising the different positions and different research questions. (Table 1)

Katie	:	So is the green moving because of something that happens within that environment? or is the green, so is it kind of moving independently of the orange, and has nothing to do with the orange cells, it's to do with the function of the green cell? . . . or the function that the orange cell carries out that stops it performing its function? Or maybe it's evolved because they are similar cells with similar functions? (Q; In-Id).

CONCLUSION

From the coding sequence we can identify three distinct discursive patterns that we denote as (a) Tutor scaffolding from tentative speculation to elaboration of a model (episode A); (b) Student problematization (episode B); (c) Developing research questions (episode C). From episode A, we suggest that the involvement of a science researcher, or a teacher strongly acquainted with the researcher's work, to help scaffold participant questions would enhance authenticity in these interactions. Throughout the discussions, it is possible that gentle scaffolding from the researcher, as seen in episode A, might have resulted in more productive outcomes. On the other hand, there is a difficult line to draw between over-intervention and successful scaffolding.

Problematization is a process of reasoning infrequently encountered in school science, "the work of identifying, articulating, and motivating a problem or clear question" (Phillips, Watkins, & Hammer, D. 2018, p.983). In episode B in particular, problematization generates uncertainty which in the end the students cannot unravel. Encouraging students to problematize requires considerable pedagogic skill: to anticipate the uncertainty, to demonstrate in this case that control experiments in complex systems require a deep knowledge of the system, and aiding the formulation of possible solutions which help students appreciate the gap between simple procedures in school science and the complexity when working on open-ended problems. Finally, in episode C a participant draws on school knowledge to propose an analogy which through a series of clarifications and elaborations results in two participants proposing a range of research questions.

The evidence suggests that when pre-university students with sufficient background knowledge are given the opportunity to discuss research problems with a research scientist, these discussions approach authenticity, and knowledge building takes place. What knowledge students need, how specialized and to what depth needs further investigation. One benefit of this task is that it allows students to use knowledge, to see how it operates in other contexts, and how it is problematized free from the possibly distracting procedures of laboratory practice.

A meta-analysis of group learning in science (Springer, Stanne, & Donovan, 1999) demonstrates that small group learning benefited undergraduate students in STEM subjects, promoting more sustained achievement, improving attitudes and academic persistence. Bennett, Hogarth, Lubben, Campbell, & Robinson, 2009) systematic review of small group discussions in school science lessons spanning the 11-18 age range advises the explicit development of discussion skills both in teacher and student education. While we do not differ from this conclusion, we suggest that the context of this task is an important way of identifying what knowledge and skills are exemplified, and therefore need support, when engaging in a research-based task. Our experience also shows that mixed sex groups operated effectively with both young men and women generating ideas and problematising ideas within the groups. It should be noted that not all Chinn and Malhotra's (2002) criteria were addressed. The scope of the problem did not allow for that. It is worthwhile considering what other tasks and their framing could promote discussions with a deeper research base, including how they might affect or be affected by the structure of the groups.

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