Critical Pedagogies in STEM Education:

Ideas and experiences from Brazil and the UK

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Arthur Galamba
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Summary

BRIDGING BRAZIL AND THE UNITED KINGDOM FOR SUSTAINABLE EDUCATION

ALESSANDRA MOURA
Senior Manager of Basic Education and English Language

The British Council works all over the world collaborating with international projects that promote more quality and equity in basic education. In addition to contributing to sustainable human development, our work is intended to contribute to peace and prosperity among people. This publication is in line with our aspirations.

During the years 2020 and 2021, teachers around the world migrated their continuing education activities to the online environment, given the limitations to face-to-face activities imposed by the COVID-19 pandemic. Educators around the world needed to review their practices not only to create remote and hybrid teaching models, but also to review the prioritization of the skills needed for their students to navigate the new times.

Scientific literacy and critical thinking were some of the skills that gained greater importance for students to understand the information related to the global health crisis that was circulating at the time. These skills are necessary for students to complete basic education with a worldview consistent with the reality. They are foundations of education for sustainable human development.

Ways to develop these and other fundamental competences at school are addressed in the publication Critical Pedagogies in STEM Education created by specialists from Brazil and the United Kingdom. The book is an offshoot of the webinar "Challenges to Implement Critical Pedagogies in STEM Education", held in June 2021, as part of the activities of the STEM Education Hub, an initiative of the British Council and King's College London. It was yet another contribution to the ongoing training of teachers in Brazil in a delicate period for basic education in the country. Many more are published at www.stemeducationhub.co.uk.

Throughout the book chapters, despite each country and each educational system having its peculiarity, all co-authors find value in the differences and similarities of their approaches. This work is the result of connections and building trust between experts who are, above all, educators, and also people willing to learn continuously.

Paulo Freire has said that there is no neutral education. Every educational action entail educators' choices. Therefore, we hope that the reading of the chapters in this book will inspire the development of a science and technology education that is stimulating, engaging and sustainable. As well as the peaceful and collaborative worldview that is championed by our organization.

PRESENTATION

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Lecturer in
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This new publication of the STEM Education Hub is yet another collaborative activity between researchers from Brazil and the UK in Science, Technology, Engineering and Mathematics (STEM) Education. The STEM Education Hub is a project run in collaboration between the British Council and King's College London. And in the collaborative and multicultural spirit of the STEM Education Hub, we are delighted that this book was co-edited by two Brazilian STEM educators from King's College London and the University of Cambridge.

The focus of this book on critical pedagogy is timely. The international community of STEM educators has been making substantial theoretical and practical development on inclusive pedagogies. Gender inclusion, decolonisation and racism in STEM teaching and professional settings are some of the concerns that researchers in this book have. As a community of STEM educators, we endeavour to teach STEM subjects without losing sight of building a fairer and more just world. Understanding what the critical issues in STEM education are is only the first step for the necessary transformation towards those aims. We must close the gap between research practice, academic debate and classroom practice. And this book aims to contribute to close that gap, hoping that teachers will read, share and discuss it with colleagues and develop ways to implement critical pedagogies in their lessons.

We are very much grateful to the British Council for the strategic, administrative and financial support to publish this book. And immensely grateful to the authors of the chapters: Bruno Monteiro, Haira Gandolfi, Cristiano Moura, Anna Benite, Clarissa Trajecto, Gustavo Faustino, Regina Vargas, Morgana Bastos, Thatianny Silva, Spela Godec, Meghna Chowdhuri, Ralph Levinson, Stephen Price, Paul Davies, Kostas Korfiatis, Olga Makoulides, Ruth Wheeldon, Edgar Miranda, Rita Vilanova, Vanessa Drago, Isabel Martins, Marcos Correa, Marcelo Rocha, Bruna Karl, Marcia Garcia and Yasmin Lanatte.

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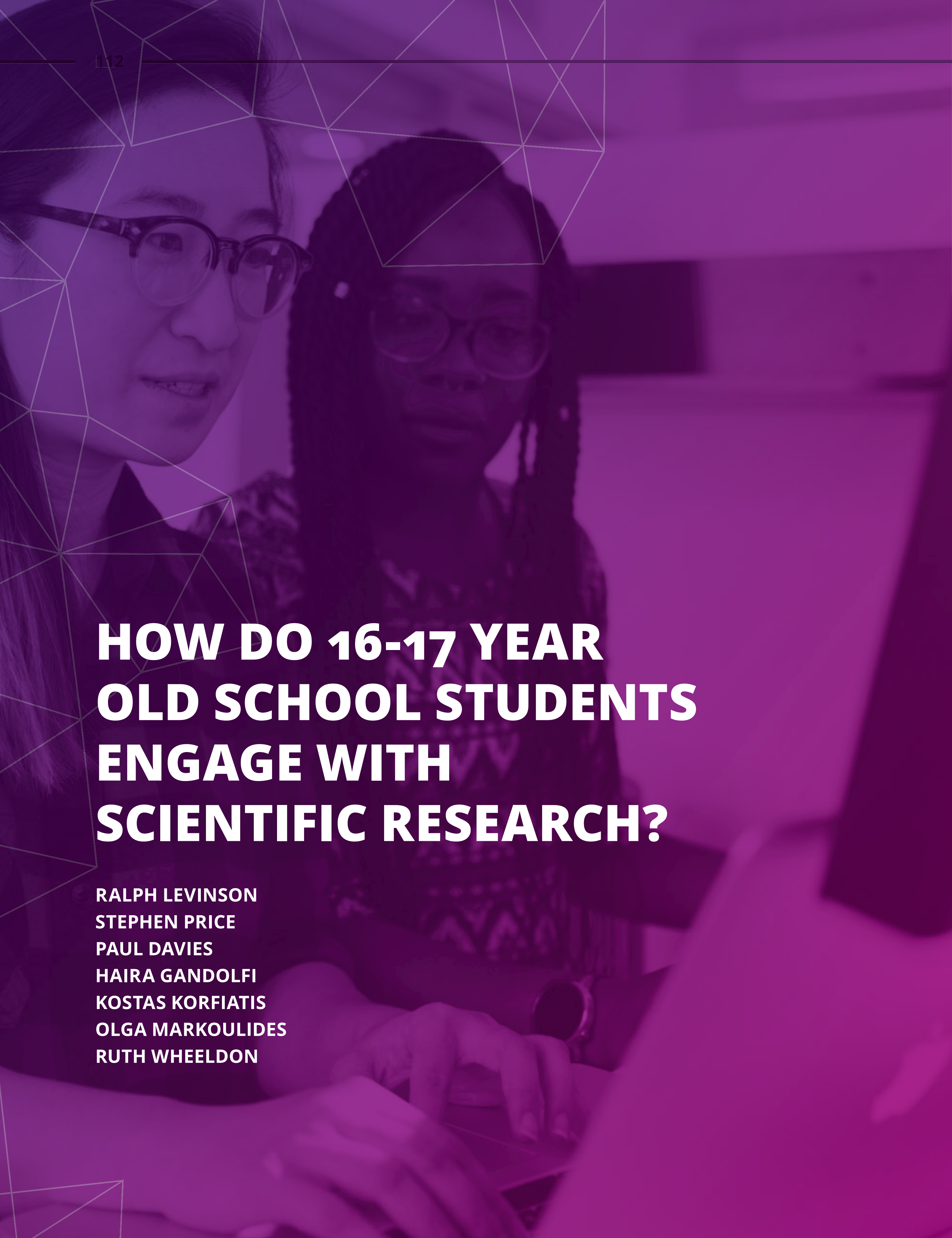


HOW DO 16-17 YEAR OLD SCHOOL STUDENTS ENGAGE WITH SCIENTIFIC RESEARCH?

RALPH LEVINSON
STEPHEN PRICE
PAUL DAVIES
HAIRA GANDOLFI
KOSTAS KORFIATIS
OLGA MARKOULIDES
RUTH WHEELDON

Abstract: Our article explores how 16-17 year old school students discuss contemporary scientific research and how they use their current school science knowledge in thinking through open research problems in biomedical science. Contemporary research problems (somewhat simplified) were presented to school groups of six participants who were tasked with discussing possible solutions. More specifically, they were asked to devise testable hypotheses and experiments to account for cell movements that form the embryonic spinal cord. An experienced researcher presented the problem and was available to answer student questions and to prompt them when they became stuck. Our analysis shows that fruitful discussions have the following three features: authoritative scaffolding encouraging elaboration, explanation and use of pupil knowledge; willingness of participants to problematise and revise suggestions; and collective elaboration of ideas sufficient to stimulate new questions. Students drew on knowledge through dialogue which problematised their school knowledge and opened-up its difficulties in application to a research task. We suggest that an openness to new ways of thinking and uncertainty in learning science rather than the STEM 'pipeline' might attract more young people from minority groups into studying science at university and open up new pedagogic possibilities in addressing science research in schools.

INTRODUCTION

Much effort has been devoted to recruiting young people to the 'Science, Technology, Engineering and Mathematics/STEM pipeline' (van den Hurk et al., 2019), deemed important for societal benefit. Pipelines convey liquids, usually petrochemicals, from one place to another; which is not the most congenial term to use throughout a time of climate crisis. This curious phrase also conjures up extreme passivity, that it is a good thing of itself to enable young people to be pumped like a liquid towards STEM careers..

Over the years there have been a number of attempts to fill this pipeline with people who are often excluded from the STEM marketplace, for example Women Into Science and Engineering/WISE, and boosting young Black researchers in STEM (Gewin, 2020). The ASPIRES research (Archer et al., 2015), also part of this book, has demonstrated the influence of social capital and habitus in supporting young people to take up STEM study and careers.

One of the problems of the transition between school science and science in higher education is that a whole new way of thinking and being has to be developed to engage in scientific research. Chinn and Malhotra (2002) have demonstrated many of the differences between science as gleaned from school textbooks and the realities of research, some of which are listed in Table 1. Of course, many science lessons are innovative and challenging so we have included only those aspects of scientific research that school students might find unfamiliar.

TABLE 1: DIFFERENCES BETWEEN RESEARCH SCIENCE AND SCHOOL SCIENCE (ADAPTED FROM CHINN & MALHOTRA, 2002)

1	Research questions	Generate or adapt own research questions	Research questions provided
2	Variables	Select variables to investigate out of many possibilities	Investigate and report on prescribed variables
3	Planning measures	Typically incorporate multiple measures of independent, intermediate and dependent variables	Focus on one outcome variable
4	Transforming observations	Often repeatedly transformed into other data formats	Drawings or straightforward graphs (if transformed)
5	Indirect reasoning (i)	Observations related to research questions by chains of inference	Observations directly related to research questions

Number	Process	Research science	School Science
6	Indirect reasoning (ii)	Observed variables not directly related to variables of interest	Observed variables are those of interest
7	Generalisations	Need to judge whether to generalise from the experimental situation to other situations	Only generalise to similar situations
8	Types of reasoning	Employ multiple forms of argument	Simple contrastive, inductive or deductive reasoning
9	Level of theory	Construct theories postulating relevant mechanisms	Either uncover empirical regularities or illustrate theoretical mechanisms
10	Co-ordinating results from multiple studies	Frequently do this	Usually single experiment, range of observations or demonstration

Those who master the ways in which success in science studies is measured, through school examinations, might not be best suited for the uncertain and serendipitous world of research. Conversely, those who have struggled with providing the "right" answer, and hence under-achieved in examinations, might just be the students who can best deal with research problems. Wheeldon et al (2012) found in the context of learning about chemical equilibrium that, when faced with solving a problem where an algorithm could not help, some lower attainers were more successful than their high-achieving peers because they had thought beyond the received wisdoms. Taken together, these works by Chinn & Malhotra (2002) and Wheeldon et al. (2012) suggest that current educational practices might be suboptimal in recruiting talented people to the research endeavour.

While most investigations on students learning authentic science practise has focused on laboratory-based activities, our intention was to study the way students elaborate explanations behind mechanisms, removing the possible distractions of a laboratory environment. Millar and Abrahams (2009) have researched practical work in school and shown that far too often pupils are following the teacher's instructions rather than reflecting upon the underlying scientific ideas that inform the practical work. Addressing this problem is central to the aim of our research. Linking the knowledge and ideas to understanding the complex natural world is surely a central educational goal.

The initiative for the research we discuss in this article was a chance opportunity. An enthusiastic biology teacher (Olga Markoulides) had approached Stephen Price (a Bioscience researcher) and asked him to talk about his research to her year 12 (17-18 year old) biology students from a socially diverse and disadvantaged area of London. These students were keen and interested so, subsequently, they and students from other schools were invited to the University College London (UCL), where Stephen Price works. We built into these visits an opportunity for students themselves to develop and formulate their own ideas in contemporary scientific research.

Although there has been little research done with pre-university students discussing mechanisms in scientific developments, there were some indications that this might be a fruitful way for students to gain a nuanced view of scientific research. Epstein (1970) reported that the use of primary research papers in undergraduate biology programmes in the United States stimulated interest in all students. Epstein identified four features for this success: students should be new to research; focus should be on the researcher's work rather than their scientific content; class sessions should be based on student questioning; and there should be no pressure on students to participate. We thus grounded our empirical research on Epstein's approach.

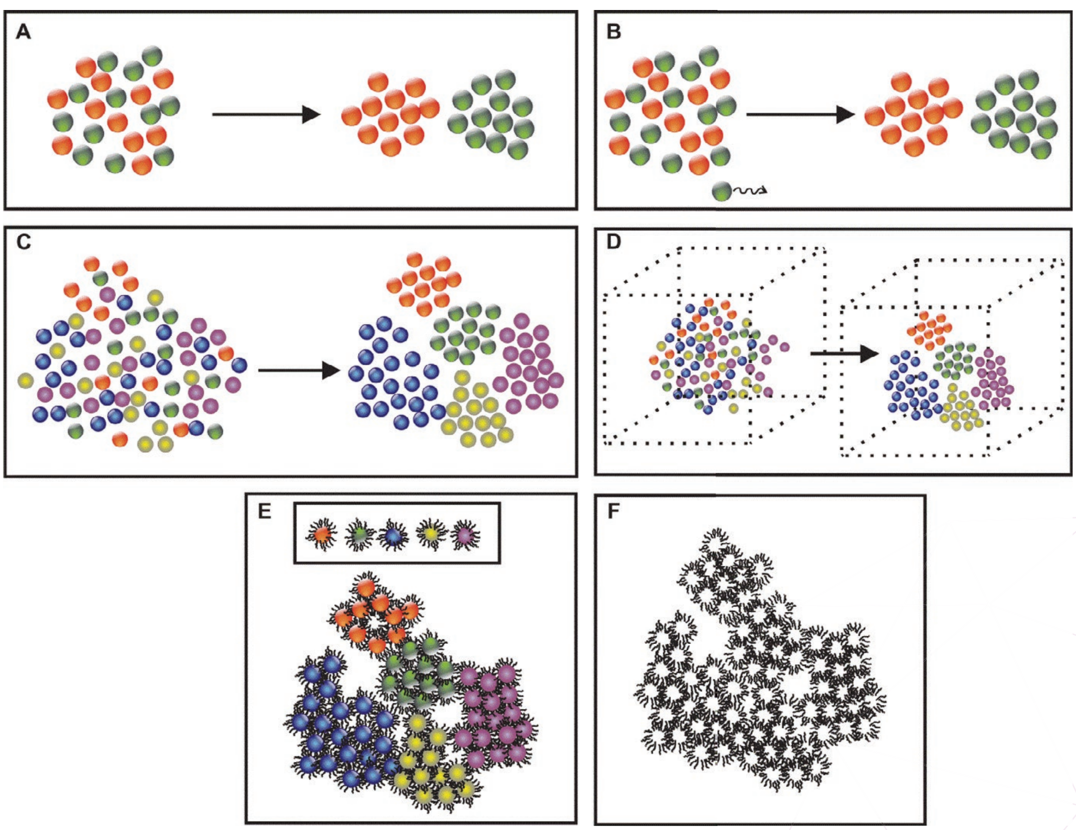
Roth & Bowen (1995) also allude to five significant features of open inquiry learning: participants learn through ill-defined problems; they experience uncertainties, ambiguities and "the social nature of scientific work and knowledge" (p.1); learning is based on what they already know; participants take part in shared discourses; and participants can draw on the "expertise of more knowledgeable others" (p.1), i.e. a research scientist or teacher. These features are present in the episodes we describe here.

APPROACH

The basis of our research was to focus on the development of ideas through discussion and on how students might draw on what they already knew; in this case cell division and differentiation at A-level standard. We wanted them to talk through ideas of a contemporary research problem prompted by a research scientist. The research problem we asked them to consider was the mechanism behind post-mitotic cell movements in the developing spinal cord of the chick embryo. As any multicellular living organism develops, cells divide and move in particular patterns. But what drives this process? How come the pattern is faithfully repeated each time?

We asked students to work in groups of six. We also made it clear that this was ongoing research, and that there were no right or wrong answers. We encouraged speculation: i.e., at first the students were told the nature of the problem and presented with a simplified model (Figure 1) to stimulate initial discussion.

FIGURE 1: SIMPLIFIED MODEL



For each stage the students were asked to suggest a possible mechanism, i.e what might explain cells with the same function separating in the same way each time, as represented by orange and green spheres (Figure 1A). They were also asked to propose possible experiments to test their hypotheses. As the discussion progressed they were shown further stages (B-F) to deepen the problem.

The discussions were recorded with the students' informed consent. Researchers also took notes sitting aside from the group. The students could ask the scientist any questions they wanted at any time, and indeed, did so. We also asked the students to complete a short questionnaire about the subjects they studied at A-level and their perceptions of scientific research both before and after the intervention. These were identified through content and word cloud analysis. Students' names are anonymised throughout.

FINDINGS

DISCUSSION

At first, we had to accept that what would transpire in the discussion was unknown. We had piloted talk about the model in Figure 1 with trainee science teachers without a background in this type of research and decided there was sufficient material at an appropriate level to initiate this project. But we were concerned that the students would run out of ideas at an early stage, boredom would set in and we would have to abandon the programme. With the first group there was hesitancy at the beginning but with some gentle scaffolding from the researcher the discussion deepened. In this article we present three episodes from the discussion from one group of students that illustrate many of the salient features of this discussion.

For the first seven minutes students had been discussing with little progress what makes the two types of cell (modelled as orange and green) separate (see Figure 1A). What we mean by little progress is that when a student makes a suggestion (initiates an idea) it is either not followed up by another participant, dismissed, or fades out of the discussion. After some hesitant student contributions, the research scientist (RS), prompting the discussion, reminds the students that the cells are in a post-mitotic phase, i.e. they have stopped dividing. So how does that influence the problem? At this point one of the students, Muna, initiates an episode with a statement resulting in a dialogue with RS, which we reproduce below.

EPISODE 1 (INITIAL SCAFFOLDING)

MUNA (F)[1]: Well something must attract all the cells to each other like all the cells that have similar characteristics together.
RS (M): Yes.
Muna: Just trying to think what that can be, that can differentiate them.
RS: OK, so something that could attract... How might that work in terms of the attraction? (Pause). What would you need to do in order to get cells attracting? Or what else would you need to do?... <eight second pause>... So you've got orange cells and green cells initially sort of randomly mixed, and then they become orange here and green there, so what might work in terms of attraction, what might...?
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?
RS: That's really good, yes, so you could imagine a scenario where there are sort of common things, but how would those common things work do you think?
MUNA: So if you are looking at the bodies, not quite sure, things like pH levels or iron levels or whatever's going on you can link together and what could attract cells.
RS: OK.

1. (F) indicates female, (M) male

In this episode, similar to initial episodes with other groups, Muna rephrases the question out loud, assisted by the research scientist, who tries to break down the question into its component parts (what would you need to attract cells? You've got red and green cells randomly mixed at first so what might work in terms of attraction?) to enable explanation. Muna tentatively attempts a general explanation 'common factors', and after RS's encouragement, suggests more specific potential causes ('pH levels', 'iron levels').

Many researchers have advocated the role of the sort of support that RS offers to help explicate fruitful inquiry questions. There is a lot at stake here for Muna, and for other students at a similar phase. They have not regularly engaged in open inquiry, certainly at research level, and there is an understandable risk of being out of their depth. Kawalkar and Vijapurkar (2013) argue that questioning in the context of inquiry is aimed not at evaluating conceptual knowledge but in eliciting students' ideas so that they can clearly explicate them and hold them up to critique by their peers.

The support of the RS, together with affirmation after tentative responses, enables Muna to develop ideas that help the group move on in its explanation. As we shall see in episode 2, which follows on directly, RS now looks to others in the group to contribute.

EPISODE 2 (CONSTRUCTING A MODEL)

RABIA(F): There might also be similarities like in the cell membranes, like it depends on like what makes the orange cell different to the green cell possibly.
RS: OK.
RABIA: So like cell signalling happens with glycoproteins, so maybe then to find signs of glycoproteins in an orange cell or a green cell could help differentiate them.
RS: OK. So what is the model that you are making, what's the model? You are saying that the orange cells are similar.
RABIA: Yes.
RS: And the green cells are similar. How does that make them separate?
RABIA: Um, there might be another mechanism in the body, that like, for example, things might like attach to the glycoproteins because I'm just like linking back to things that we've done in school, with like antibodies and stuff.
RS: Yeah.
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.
RS: OK.
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.
RS: OK. Very good. So if we put that model together, what does the rest of the group think about that as a model? You've got proteins which are on the orange cell and proteins which are on the green cell, that could be sort of antibody-like, that make the orange cells look orange, and the green cells look green. So can I get you to discuss that model? And how you might find out if that model was right or not?

In episode 2 RS supports Rabia in explicating in sufficient detail to construct a testable model. There are three points to note about Rabia's intervention.

i. Her suggestion does not follow from any fact or idea that Muna has proposed. Whereas Muna has suggested environmental factors might be responsible for cell separation and organisation, Rabia focuses on a structural aspect, the cell membrane. It is not the concepts, therefore, that are central here but the discursive opening up of ideas.

ii. RS works initially on helping Rabia to detail her model as fully as possible by repetition, rewording and reassurance.

iii. Rabia draws on her school knowledge – glycoproteins in the membrane responsible for cell signalling, antibody-antigen interactions – to develop the model.

By the end of this episode, a workable model is now presented for discussion. In terms of research science (table 1), a theory has been constructed, postulating mechanisms with unobservable entities, e.g. molecular bodies attached to proteins in the cell membrane. Rabia also draws on her knowledge of school science about antibody-antigen mechanisms and uses this as an explanatory model.

While not all discussions relied on a research scientist to support initial explication this was true of the majority of discussions. Note that the researcher's role is not in producing new information but through rewording and affirmation to support confidence in advancing an idea.

Episode 3 follows directly on from episode 2 where the group test the model as RS has asked. Muna again initiates the discussion.

EPISODE 3 (TESTING THE MODEL)

MUNA(F): We could take away the membrane and see if the same thing happens, so if there is something on the membrane that differentiates them from being green and orange, and then take that away and if they keep on dividing then we know, OK, so there's something different other than the membrane.

NITA(F): Yeah.

DON(M): So how do you test for it?

MUNA(F): How would we take away the protein you mean, like...

DON(M): Yeah, but what if you can't identify the protein?

MUNA(F): How would you test for protein, so we can't see it under...?

DON(M): No. so like what if you know there's a protein but you don't know which protein causes the change?

NITA(F): Yeah, because that's true, it's not like cells have just one, like the whole, yeah...
MUNA(F): Can't we check like DNA sequences inside of it, and see then what codes, what codes it?
DON(M): Yeah, but if we don't know what protein we are looking for then we don't know what basis to look for.
MUNA(F): Oh OK OK. How could we test that? <10 second pause> We could look for common practice, and if we've loads of proteins on then we first see what's the same and then we can cancel those out and continue in that way.
DON(M): What about if we denature the proteins... 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...
MUNA(F): Yeah, that would be good. But what would that...?
NITA(F): That would affect the specific protein you are trying to target.
MOH(M): But we could just denature it, like if it still goes through there's no protein in it, so...
NITA(F): Right. Cause the cell to...
MOH(M): So the cell breaks but there's no protein to denature.
NITA(F): But would it be possible to denature the protein without affecting how the cell works? I think that changes too many factors <9 second pause>
DON(M): So can we identify the protein? Or know exactly what protein it is? Or say that it is a protein?
NITA(F): You don't know that it's a protein.

In episode 3 a space is created to acknowledge complexity and failure. The model is discussed but they fail to provide any suggestions for empirically testing the model successfully.

Muna starts once again by suggesting that an active protein in the membrane might be responsible: remove the protein and see if the cells behave differently. But this is where the complexities of scientific research become evident because Don asks how one would identify the protein. There are many different proteins in the cell membrane and how do you distinguish whether it is just one acting, or more than one? And how would one know which protein this is? He suggests an alternative approach: denature the proteins, presumably by heating or changing pH. This would test whether proteins in the membrane are implicated. But here Nita's interventions are crucial: effectively you can't separate off the functioning of the cell from the protein activity.

Nita has identified a central problem and one which also distinguishes school science from research science. In school science received knowledge is often passed on as illustrative where the variables are distinguished and controls can be simply applied (see numbers 5, 6 and 7 in Table 1). So, for example, the effect of light on a seedling can be explored by subjecting some seedlings to light and not others. Any difference can be accounted for by the effect of the light. Light operates as a single discrete variable. But the same cannot be said about the proteins – because proteins are essential to all the functions of the cell, removal of all proteins will reveal nothing as the cell would not survive.

The students were then not able to suggest examples to test their model but this is far from a failure. What they have learned as evidenced from the answers to the questionnaire, and later reports from teachers, is that scientific research is about trying to solve seemingly intractable problems through collaborative – and dissonant – thinking, what is referred to as exploratory talk (Mercer & Dawes, 2008). For the students this aspect of research as collaborative problem-solving introduces a new dimension to their expectation of studying science at university, one which they see as exciting and full of possibilities.

QUESTIONNAIRE RESPONSES

Students were asked to complete a statement 'To me the purpose of research science is to' both before and after their discussion of the contemporary research problem. Initial analyses of the responses are indicative: students pre-intervention responses focused on 'increasing knowledge and understanding of biological processes', or 'solidifying knowledge' but after the intervention new terms such as 'complex decision-making', 'serendipity', 'uncertainty', 'a lot of unknowns', 'flexibility' were used.

It suggests that once students have had a chance to explore research problems discursively, they begin to entertain doubts about the certainty of the knowledge they have, and that revelation somewhat paradoxically unveils what is not known, a key feature of research.

Teachers mentioned that those students who were not high academic achievers surprised them in their fruitful and perceptive contributions to the discussion. We also found that the main source of rebuttals and initiating new ideas came from students who studied at least one non STEM subject for their A-level examinations.

THE QUESTION OF KNOWLEDGE

Some years ago one of the authors had a residency with a large chemical company. A senior manager in the company told him about their strategy in employing analysts: sixteen year olds from school brought an intelligent freshness to problems which often evaded those with postgraduate science degrees. Too much knowledge appeared to conceal obvious solutions. The manager claimed that young recruits straight from school often had a 'sixth sense' borne of practise which enabled them to quickly detect problems and find solutions. If you asked them how they did it, he added, they probably wouldn't be able to tell you. Their knowledge is tacit.

The point about this story is not to debunk knowledge. On the contrary knowledge is important and depends on the context in which it is used. For example, here, Rabia draws on her school knowledge to help her devise a functional model, namely that glycoproteins in the cell membrane might have a determinant role. But all the students are hindered by the fact that they cannot think of a way to validate or refute this model. It did not matter that they did not know how to use sophisticated techniques – the researcher could help them think about these – but that the ways in which they had thought about procedural inquiry in schools could not help. Failure stimulates new opportunities.

Ryle (1945) raised the question of "knowing that and knowing how", one that has been chewed over by philosophers and science educationalists, particularly in relation to inquiry and problem-solving. According to Ryle, to 'know that' is to know a proposition, for example, hydrogen has an atomic number of 1 or magnesium is a metal. To 'know how' is to act or do something with that knowledge.

But this distinction between knowing that and knowing how raises all sorts of problems. For example, what precisely does a driver need to know to drive a car safely – clearly not the intricate mechanics of the car. Much of the knowledge they will derive from experience, simply by driving first in safe empty spaces and gradually accustoming to busier roads. So experience helps to provide a structure and meaning for the knowledge we gather. For example, a child who has seen their parents stir sugar into tea has noticed things that help give meaning to the concept of dissolving.

'Knowledge that' forms the basis of many testing regimes as it has the advantage of being easy to measure. As the students discovered in this experience, researchers need knowledge but they work in professional and social contexts endowing them with the skills and experience – the wherewithal – to address problems which are intractable to school students. To attempt to solve the problem of cell movement the researcher needs to know relevant knowledge about the structure and physiology of cells as well as procedural knowledge. But the failure the students experienced in being unable to provide relevant empirical evidence for their theory, makes clear to them the importance of knowing experimental procedures as well as the related theoretical knowledge which supports their quest for an explanatory model. Hence we argue that discussing contemporary research problems enables students to "know how" which gives a reality to the need for and excitement of scientific research.

CRITICAL PEDAGOGY

Why does this approach have possibilities for a critical pedagogy? One of the purposes of schools is to socialise students into disciplinary thinking. But this process of learning presupposes a kind of unavoidable tyranny – incorporating a world that has been created and moulded by others, e.g. learning a language, the symbols of the elements in the Periodic Table, the role of the heart. Of course, all this is unavoidable but, as Arendt (1993) points out, the paradox is that each generation grows into the world of the older one. She coined the term 'natality' to open up this problem: is it inevitable that the political, economic and indeed epistemological structures of an older generation constrict the possibilities of renewal for those not yet born? Do established certainties, laws, theories and principles staunch the possibilities of more fruitful thinking?

Critical pedagogy, drawing on Freire, makes visible the sources of oppression of ideas and the tools to overcome that oppression. But the very tools that we use – language, knowledge, ideas – are those that emanate from power and hence oppressive structures. To abandon that knowledge would be utterly self-defeating. Here, we draw on critical pedagogy to raise awareness of the problem of the "banking" model of education: new knowledge is not an asset to deposit for social and political status but is always contentious. New knowledge should be conjoined with experience to open up new ways of explaining the world. In this study, we bring into tension within the pedagogic frame the relationship between learning science in school and doing scientific research. Opening up new discursive spaces has then the potential to influence how science is taught at school.

Much of school science follows the banking model wherein knowledge from an authority, e.g. a teacher or lecturer, is transmitted as authoritative knowledge to a learner, often to be reproduced in tests and examinations. As we have seen, however, students need support in using this knowledge to address new types of questions, in this case, in research science, but when they do so they become aware of its limitations. This, in itself, is an empowering process.

IMPLICATIONS FOR PEDAGOGY

From our research we claim that exposing students to contemporary science research problems alerts them to the uncertainty and tentativeness of scientific knowledge but also to its value. It opens learning avenues for those who have not necessarily considered following a science course at university, but who crucially have the excitement of looking at nature from a different, and differently, informed perspective.

We understand the difficulties for teachers to generate group discussions about contemporary research. As we have indicated, students might well be hesitant at first but patience and a willingness to make mistakes can reap unexpected benefits. One of the future directions of this research study is, therefore, in supporting teachers or willing research scientists in running these discussions in classrooms. The biomedical faculty at UCL, for example, has developed research problems for potential bioscientists to discuss (UCL 2021) covering topics such as dealing with plastic pollution, the possibilities for further study and use of light activated proteins, and secrets of biological survival of tardigrades.

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