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Students' Forms of Dialogue When Engaged with Contemporary Biological Research: Insights from University and High School Students' Group Discussions

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Abstract
Classroom dialogues have special educational value because they allow students to engage critically but constructively with each other's ideas, solve scientific problems jointly and develop their scientific understanding. The present study focuses on how groups of twelfth-grade high school and university students communicate and co-operate through dialogue to solve a biological problem they have not encountered before. The specific research questions are as follows: (a) What are the dialogic structures that help students construct scientific explanations? (b) How does prior scientific knowledge support student dialogue in constructing explanations? A coding scheme was developed inductively for the analysis of participants' utterances. We use illustrative exemplars from participants' dialogues to discuss those aspects which might support explanatory reasoning. We focus on reasoned attention for contending opinions and striving for consensus that characterise cases of constructive dialogue. We also discuss observed objections and disagreements as triggering factors for constructive alternative explanations. Finally, we discuss the evidence showing that while prior knowledge supports student reasoning it can also hinder the ability of students to think in a creative way.

Keywords Students' dialogues in science education · Forms of dialogue · Use of scientific knowledge · Constructive dialogues · Exploratory talk

Research on classroom dialogic interactions has flourished since the 1970s (Howe and Abedin 2013). Dialogue allows students to co-construct knowledge and meanings, develop intersubjectivity (Hennessy et al. 2016) and engage participants in scientific practice, prompting them to bring what they already know to the exchange (Kuhn 2015). Classroom dialogues have been shown to influence critical thinking and have been effective in promoting democratic citizenship and peaceful living (Kazepides 2012; Aasebø 2017).

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Attunement to others' perspectives and continuous co-construction of knowledge through sharing, critiquing and gradually reconciling contrasting ideas are considered to be forms of dialogue that are productive for learning (Littleton and Mercer 2013). Sedlacek and Sedova (2017) cite Lefstein and Snell (2014) that, in order to maximise learning, active participation through a rich and stimulating discourse should be encouraged and conditions for it should be created. Mercer (2000) highlighted the key role of dialogue as 'a social mode of thinking' that allows participants to solve problems jointly, and in which students take responsibility for co-constructing their understandings. Dialogic interactions have special educational value, in that students engage critically but constructively with each other's ideas (Mercer and Littleton 2007).

For science education in particular, dialogue enables students to develop their understanding of scientific ideas. Ryu and Sikorski (2019) argue that the Next Generation Science Standards (a set of standards developed in the USA to improve science education for all students) contain a strong focus on rich learner discourse and that, in this context, researchers and educators need tools to gauge students' progress in participating in science discourse. They also argue that talking is not only evidence of scientific sense-making, but it is scientific sense-making itself. A critical purpose of science discourse is for learners to develop and refine their ideas about natural phenomena together. Envisioned this way, science inquiry is fundamentally an act of language (Ryu and Sikorski 2019).

Students often learn science as facts and definitions to memorize, so they often find it difficult to communicate and negotiate scientific processes (Ebenezer and Puvirajah 2005). Strupe et al. (2018) argue that in many laboratory inquiry classrooms, students are positioned as technicians who have to follow certain 'cookbook-like' steps. In that way, they do not shape their knowledge production and they do not participate in the practices of the scientific community. The authors suggest that students should have opportunities to learn science differently from memorizing facts and conducting confirmatory activities; it is important to create learning environments which would establish links between students and science ideas. Dialogue and collaborative learning environments are important tools for school students to construct scientific knowledge and understand how science works (McLellan and Soden 2004; Schwartz et al. 2004). Recent studies have shown that engaging in dialogue and working with peers in groups to solve unknown problems promote scientific reasoning and improve their problem-solving skills (Topping et al. 2011; Gillies and Haynes 2011). Bierema et al. (2017) found out that high school students tended to work together to clarify concepts they did not understand and used ideas suggested by their peers to build on their previous knowledge while they had been working on the development of scientific models.

Asking questions and exchanging arguments are other elements of scientific practice that students engage in when they solve scientific problems in groups. Questioning is a useful tool for initiating discussions, clarifying scientific concepts and often leading to conceptual understanding of natural phenomena (Chen and Steenhoek 2014). Research by Chinn et al. (2002) showed that questioning helps the co-construction of knowledge; questions asked by one group member could help another member overcome misconceptions or reveal a new line of thinking. Similar results were also produced in a study by Gillies et al. (2014), in which 108 students from five different schools participated.

Despite growing international evidence for the educational value of peer and pupil-teacher dialogic interactions in the classroom, the research has been mostly conducted in primary schools, maybe because teaching approaches in elementary schools are more conducive to dialogue (Higham et al. 2014). It has also been pointed out that school culture usually expects participants to follow a particular set of conversational 'ground rules' that discourage students' reasoning, question posing and evaluation of peers' responses (Mercer and Howe 2012). Besides, most of the studies focus, according to Mercer and Howe (2012), on (a) student–teacher interactions rather than peer interactions, and (b) evaluation of certain educational 'models' for facilitating dialogue, rather than on the exploration of the ways participants in the dialogue construct meaning and achieve knowledge. Last, but not least, a very small part of the literature deals with the forms of dialogue in science education.

The present study focuses on how groups of twelfth-grade (16–17 years old) high school and university (aged 20–21) students communicate and co-operate through dialogue to solve a biological problem they have not encountered before. Investigating how students react when asked to address unknown scientific problems, and trying to make sense of the forms of their dialogic interactions, can provide valuable insights into how to make science more understandable and relatable for students (Bell et al. 2003). Trying to make sense of research data which goes beyond science learned at school (Chinn and Malhotra 2002) is a collaborative process because students need to test their suppositions. It requires support from a more knowledgeable other and critical co-inquiry from their peers. Mercer et al. (2004) have named the set of conditions that could support meaningful and fruitful discussions between students' 'exploratory talk'. These involve participants making their reasoning visible; everybody is invited to contribute: opinions and ideas are respected and considered: challenges and alternatives are made explicit and are negotiated and consensus is sought before any final decision or action. Hence, we identify the nature of those interactions that reflect exploratory talk.

A feature that many authors considered as an important feature of constructive dialogue is the use of prior knowledge. Kater-Wettstädt (2018) showed that high school students participating in her study acted as potential experts on the basis of their prior knowledge in order to cope with a complex scientific problem. Similarly, Rudsberg and Öhman (2015) and Andersson and Öhman (2017) concluded that knowledge played a crucial role in students' discussions on the urgent character of environmental problems. Other authors suggest that it is the teachers' responsibility to create conditions during classroom discussions that will help students make connections between their previous knowledge and the problem they are discussing (Cian and Cook 2020; Strupe et al. 2018). In our study, we explore how extant knowledge can enhance explanations of a contemporary research problem.

We follow a socio-cultural perspective, which highlights the intrinsically social and communicative nature of human life. Sociocultural theory posits that education and cognitive development are cultural processes enacted through interactions with others, including symmetrical (peer) as well as expert–novice (e.g. teacher–student) relations (Hennessy et al. 2016). Language plays a key role as a tool for thinking and a mediator of activity, on both the social and psychological planes (Mercer 2000). The sociocultural approach is promoted by a growing body of literature in the study of classroom dialogues (Sedlacek and Sedova 2017; Hennessy et al. 2016; Howe 2010). According to Mercer et al. (2004, p. 360), educational researchers who adopt a sociocultural perspective have commonly depicted science education as a discursive process.

Specifically, our research questions are:

(a) What are the dialogic structures that help students construct scientific explanations?
(b) How does prior scientific knowledge support student dialogue in constructing explanations?

Methodology

The study was carried out at the Department of Biological Sciences and the Department of Education of a university in Cyprus, where three group discussions with secondary school students and two group discussions with university students were held. The participants were invited to address a research question on the separation of cells in the embryonic spinal cord of the chick which the fourth author of this paper, a developmental biologist at University College London, has been working on for the past 20 years.

Participants

Each group consisted of six or seven participants (Table 1). Two of the groups were comprised of third-year university students, aged 20–21 that, at the time, were studying at the Department of Education of a university in Cyprus (groups D and E). The remaining three groups were school students, aged 16–17, from two high schools in Nicosia. Each group consisted of students from the same school; two groups with students from a private school (groups A and B) and one group of students from a public school (group C). With one exception (group E), all groups were of mixed gender, but culturally and ethnically homogeneous, consisting of members of the Greek-Cypriot community.

All participating students had background knowledge of cell biology (including cellular structure and functions, mechanisms of cell division and cell signalling), obtained during their school biology lessons. However, university students had not had any contact with cell and developmental biology topics during their university studies.

Convenience sampling was used to select the participants. All participants were asked if they would like to participate in a group discussion with a research biologist at the university. Participation was entirely voluntary and students were sent a letter explaining the research and that they could opt in or opt out. Written permissions were provided by the two schools' principals, as well as by the Secretary for Secondary Education, Ministry of Education, as it is the official procedure for conducting research with underaged persons in Cyprus, allowing participation of high school students in the specific research. Participants gave their written permission to be audio recorded. The discussion was in English and translation in Greek was provided, when necessary, by the first two authors who were following the discussion.

Procedure

The discussions with the groups of school and university students took place over two separate days. Each session lasted approximately 90 min and the discussions were

Table 1 Features of each group

School	Group	Participants' number and gender make-up
High school 1	Group A	7 (4F:3M)
	Group B	6 (3F: 3M)
High school 2	Group C	7 (3F: 4M)
University	Group D	7 (6F: 1M)
	Group E	6 (F)

audio-recorded. The participants were not aware of the topic of discussion before they arrived at the university campus and therefore were not able to investigate the topic beforehand. At the beginning of each session, the fourth author of this paper (named as the 'scientist' for the rest of the paper) introduced the research problem he is currently working on: post-mitotic motor neuron separation in the developing neural tube. The topic was simplified and presented gradually in order to ensure that all participants would adequately understand the information that was provided.

The presentation of the research problem consisted of six slides and the researcher introduced each slide (see Fig. 1) with a short verbal description in English. After the presentation of each slide, the participants had to discuss in their group how to account for the phenomenon and suggest ways to test their ideas. At the end, one student summarised their ideas to the scientist and then they were shown the next slide, which added a level of complexity to the problem. When appropriate, one of the first two authors translated participants' ideas to the scientist.

Discussion was operationalised in the following sequence: The phenomenon of cell separation in the embryonic spinal cord is found in tissues of all animal species, represented in a figure showing two different cell types of two sets of spheres coloured orange and green respectively (Fig. 1a). The slide shows the spheres initially as randomly intermingled with the two coloured spheres segregating into two distinct groupings over time. The students were asked to explain segregation and clustering of the two different post-mitotic cell types. After each sequence of discussion, a member of the group summarised the group's thinking. Subsequent slides introduced additional complexity on cell segregation. The second slide

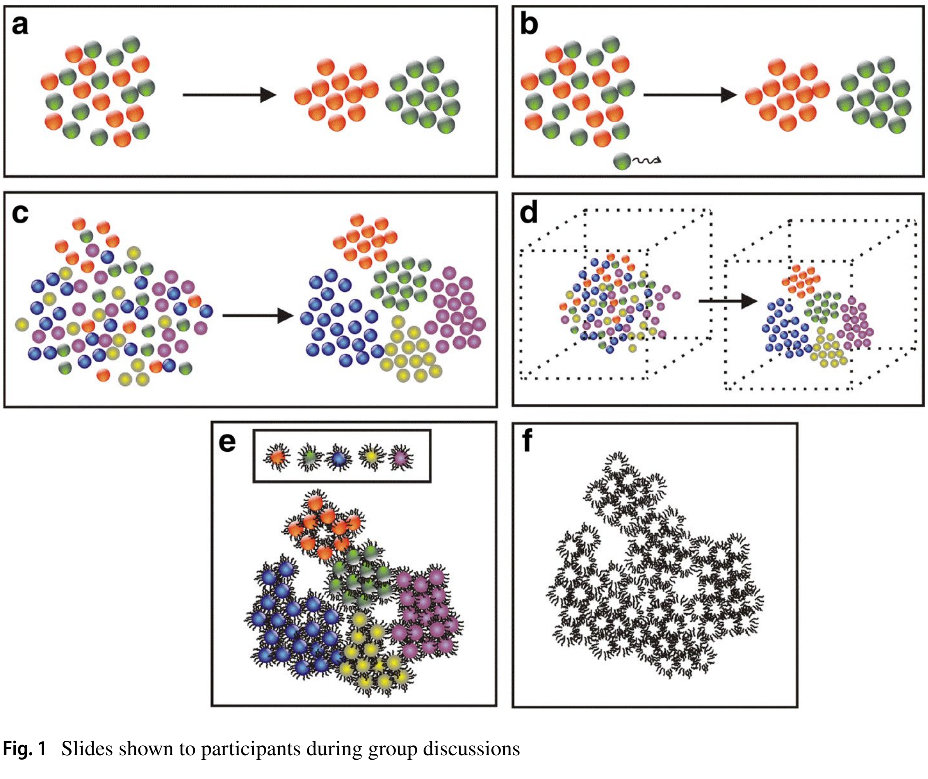

Fig. 1 Slides shown to participants during group discussions

(Fig. 1b) represented movement of the 'green' cells translating from left to right under an internal motor. The third slide (Fig. 1c) showed five different cell types when the students were told that the cells were motor neurons of the spinal cord, and the segregation and clustering were core to their development. The fourth slide (Fig. 1d) modelled the process occurring in three dimensions. Finally, Fig. 1e and f displayed current thinking about the problem: dendritic elaborations of motor neuron membranes might play a key role in driving clustering and segregation.

Participants could ask the scientist any question they deemed necessary at any point.

Data Analysis

The audio recording of each discussion was transcribed.

A coding scheme was used for the analysis of the transcriptions resulting in five code maps, one for each group. The coding scheme (Table 2) was developed inductively and it was gradually refined through interaction with the transcripts. The first three authors 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. Once the codes could describe all of the data satisfactorily, the coding schemes were established and all of the transcripts were recoded using the final schemes.

A code was assigned to each utterance of students, in order to be able to analyse their dialogic interactions. All code maps were then studied for the identification of common patterns and differences in students' interactions while working in groups. The identified patterns were then used for answering the research questions of the present paper, namely the exploration of the dialogic structures that help students construct explanations and the use of prior knowledge.

We make no general claims arising from the analysis; we rather use illustrative examples for identifying fruitful dialogue in proposing explanations. In the 'Discussion' section, we highlight those aspects which might support explanatory reasoning where students engage with open questions in scientific research.

Results

We have divided our results into two broad categories, in accordance with the research questions: forms of students' dialogue and students' use of prior scientific knowledge when attempting an explanation.

Forms of Students' Dialogic Interaction

Constructive Dialogues

In this sub-section, we present instances of constructive dialogues, i.e. where students build explanations through discussion.

Table 2 The coding scheme used to analyse the transcriptions of each group

Code	Statement type (code)	Description	Example
NS	New suggestion	Suggesting an idea for the first time, not previously heard in the discussion	‘The orange may have a chemical substance that attracts one another.’
PK	Use of prior knowledge	Use of prior knowledge obtained from biology or other fields to solve the research problem	‘So they can take embryonic hormones and add them in the injection.’
El	Elaboration	Analysis of an idea in further detail to better explain it	‘Yes and the protrusions join together and they become orange and green.’
Ex	Explanation	Statements used to clarify ideas or claims; usually an answer to the question ‘how’	‘... Yes that’s why they separate, so they can perform different functions.’
A	Assent	Agreement with opinion of others	‘Yes, that’s what I thought, too. Hemoglobin.’
Q	Question: Qc – clarificatory; Qo – objection; Qe – elaboration;	A participant poses a question; there are different types of questions: - Clarificatory question: used for clarifying a point in the discussion - Objection question: used for disagreeing with a point made during the discussion - Elaborative question: used for asking further explanation of a point or an idea	‘Does the cell have to do with charges? Do they have charges?’ (Qc) If they have receptors and, through substances, they only recognize the cells that are the same, they all become a group…yes, but why do they separate later? (Qo) So is there a connection between the orange and the green? Do the orange drive the green away, repel them? Is that why the green are leaving? (Qe)
R	Response	Replying to a question, claim or evidence proposed by another participant	‘Yes the greens are moving from left to right.’
O	Objection	Disagreement with opinion of others	‘Yes, but we don’t know how that works.’
Rpt	Repetition	Repetition of an idea previously discussed by the same or another participant	‘This may be why they separate at the end; each group separates from the other.’

Extract 1: Cumulative Talk

Group C are discussing the first slide where post-mitotic cells separate from a ball of cells into distinct groups (Table 3). Student S4 initiates the sequence suggesting that they should explore 'the legs' which help the cells clump together. What follows is a series of utterances in which one student adds to either an explanation or an elaboration by the preceding speaker. A picture of the separation process is pieced together as each utterance takes into account what has gone before.

We exemplify this as cumulative talk (Mercer and Littleton 2007). There is an implicit commitment by each contributor to build an explanation but without any critical evaluation of reasons that have been given; there are no objections. However, it's importance is in providing a coherent body of knowledge which can be examined.

Extract 2: Critical Elaboration

Because the discussion presented in Table 3 had not yet produced a convincing mechanism, the group continued the discussion (Table 4). S6 suggests there might be repulsion between the two bodies of cells (U11), and S5 (U13) follows this by suggesting the separation might be due to the fact that orange cells have different receptors on their surfaces from green cells. S1 then asks a clarificatory question (U14) which encourages a more specific explanation. S6 raises a problem (U16) which results in an explanation that integrates all the ideas being proposed by the team (U19-21).

This extract approaches the conditions of exploratory talk in the sense that there is a commitment by the group to find an explanation through critical elaboration, but without disrespecting other opinions.

Extract 3: Problematizing Suggestions

Group C offered another instance of a fruitful and constructive form of dialogue, which is based on the problematization of the original suggestion(s) (Table 5). When the scientist presented the second slide and the new information that there is movement of the green cells from left to right, the first response from student S3 (U1) was a clarificatory question (does the green cell have a leg?), which at the same time was a suggestion that the green cells move because they have legs. Two students raised objections to the suggestion either by questioning (U4) or presenting counter-evidence (U6). Those objections encouraged S3 to make an improved suggestion (U7). Student S1 completed the explanation (U8).

In this extract (Table 5), the students who problematized the suggestion, i.e. provided an objection, triggered the generation of new ideas and the proposed solutions reached. Problematizing suggestions and formulating new ones helped the group elaborate their explanation in line with the evidence.

Extract 4: Questions

In another instance, group E concluded in the discussion of the first slide that the separation of the cells into green and orange is due to the different 'substances' of the cells by which they mean the chemical composition. When the second slide was shown, they

Table 3 Extract of group C's discussion of the first slide (how green and orange cells separated and clump together)

Utterance (U)	Participant	Text (coded units)	Code
1	S4	The legs may be how they behave in the end. After they.. how they separate	NS
2	S1	And how they clump together	El
3	S2	Yes, or maybe they are in a liquid and move where they have to…	Ex
4	S3	The cells may have protrusions, pulling one another and then once they are joined together to.	NS El
5	S1	Yes and the protrusions join together and they become orange and green	El
6	S6	They only join with those they have to join. That's why they separate	Ex
7	S3	And let's say they're in a liquid, if this clumping is made, it makes sense to separate	El Ex
8	S1	Everything seems so logical	A

Table 4 Extract of group C's discussion of the first slide (they continue the discussion presented in Table 3)

Utterance (U)	Participant	Text (coded units)	Code
9	S1	What was the other one?	Q
10	S2	Liquid, legs, forces	R
11	S6	They may repel each other, that's why. And they remain separated	NS Ex
12	S1	This may be why they separate at the end; each group separates from the other	Rpt A
13	S5	The orange may have several receptors that the greens don't and.. send substances Recognize in that way.. and stick with the legs you mentioned [laughter] together	NS PK
14	S1	They have different receptors?	Qc
15	S2	Basically, yes. The… receptors. And so they repel those they shouldn't clump with and they clump with those they should	R Ex
16	S6	If they have receptors and, through substances, they only recognize the cells that are the same, they all become a group. yes, but why do they separate later?	El, Ex Qo
17	S2	Because they're in a liquid	R
18	S6	This is a given	A
19	S2	Because they cannot clump with each other	Ex
20	S3	Because they are different.. substances. So they don't want to be close to each other	Ex
21	S1	Yes, those that look alike come closer	A El

Table 5 Extract of group C's discussion of the second slide (the green cells move away from the orange cells)

Utterance (U)	Participant	Text	Code
1	S3	Does the green cell have a leg?	Qc
2	S4	Yes	R A
3	S5	Those that move	R El
4	S1	Yes, but do the others stay still? Do we know that?	Qo
5	S1	No we don't, but.	R
6	S6	But the orange clump together	O
7	S3	So maybe these cells generally clump together, regardless of colour, the greens just tend to go in one direction.	NS
8	S1	And they force the rest to come the other way	Ex

had to explain why the green cells are moving away from the orange cells. For that, they were engaged in a discussion, which is mainly supported by the questions made by one student and helped the other students to offer new suggestions or explanations (Table 6). Student S9 posed the question (U1). Two of her classmates provide explanations based on the existence of repellent forces and different substances (U2, U3). But S9 persists with clarificatory and explanatory questions (U4, U7, U11), and her classmates try to respond (U4–6, U12, U14). This is a different form of explanatory talk in which one student contributes a series of rebuttals (*Qc*s) which prompt new explanations.

Non-constructive Dialogues

So far, we have provided examples of constructive dialogue where students build up explanations for evaluation. However, parts of the talk were non-constructive because suggestions were ignored, rebutted without reason or the task itself became trivialized when students felt they were out of their depth. Non-constructive talk was not necessarily oppositional; on the contrary, too often, suggestions were met with assent without any justification. Alternatively, objections were made without support.

An extract from group D:

S1: I can't think of any other thing that makes them stay together. That's what I can think of, I don't…. they somehow have to clump together in groups.
S3: I'm telling you, there are substances.
S1: Yes but what are those substances?
S4: It has substances, yes?
S1: And alcohol [laughter].
S7: It has some substances that..
S4: What's the reason?
S7: Hormones.
S1: Yes, but where are they secreted? It's very general.
S7: It's general.

Table 6 Extract of group E's discussion of the second slide (how green and orange cells move far from each other)

Utterance (U)	Participant	Text	Code
1	S9	The point is why they're moving, isn't it? Let's say that they're endogenous and exogenous, why do they move though? That's the whole point	Qc
2	S10	Because they have repellent forces	R NS
3	S11	Because they have a different substance essentially	R NS
4	S9	Yes, but is the substance that causes them to move?	Qc
5	S11	Apparently yes [laughter]	R
6	S10	Forces. Repellent [laughter]	R A
7	S9	So is there a connection between the orange and the green? Do the orange drive the green away, repel them? Is that why the green are leaving?	Qe
8	S8	Basically the green are repelled. The green want to separate, since the green are moving	R Ex
9	S9	Yes, so the orange repel them	A Ex
10	S10	Yes the orange	A
11	S9	They're there and they clump together and the green leave, okay?	Qe
12	S10	But for them to leave, something's repelling them	O
13	S9	So there's a connection between them	R NS
14	S10	Yes there is a force	R Ex
15	S9	The orange repel the green for some reason and the green leave and move	Ex

Although S1 does not ask a direct question, they imply they are struggling for an explanation which S3 provides. S1 asks S3 to be more specific, hence the seeds of constructive dialogue, but the responses become one-word suggestions without any reasons.

Use of Scientific Knowledge

Participants in all groups used knowledge obtained from school science topics and disciplines to suggest a solution to the problem. In most cases, they drew on topics they had studied in biology, chemistry and physics, such as the concept of charges or chemical substances. This was particularly evident during the discussion of the last three slides, when the scientist specified that the cells are neurons and have dendrites. Since the nervous system is a topic taught in schools in Cyprus, most students were familiar with the concept of dendrites; as a result, they were trying to remember what they know about neurons and dendrites in general.

There were three distinct ways in which participants related to scientific knowledge in attempting to find a mechanism for the separation and differentiation of cells:

i. A negative response. That was more obvious in the case of the university students, since they have not studied cell and developmental biology during their university years.

   Characteristic of this is the reaction of student S3 from the university group D, at a point where the whole group looked confused: ‘Guys, I think something very,... sorry I'm interrupting, it's a lot simpler because we don't know Biology and we speak very biologically. It's just an explanation that's easy to find. We just think too much, that it's something very difficult and that's why we end up here’. This comment explicitly suggests that they should stop feeling helpless because they have forgotten their school biology.

ii. A reference to biological concepts, for example, dendrites, but without being able to use that knowledge to explain a mechanism. This was evident in group A's discussion (Table 7)

   The discussion shown in Table 7 took place at the beginning of the discussion of the fourth slide, where the scientist had just introduced the concept of motor neurons having dendrites. After the researcher added new information, the students tried out what they had learned about neurons in class, instead of relating them to the problem they had to solve. Although most utterances sought to draw on prior scientific terminology, there were few elaborations or questions to enable competent explanations.

iii. An ability to use knowledge to tentatively move towards an explanation.

An example of this occurred in group D, supported by the researcher (Table 8).

The researcher asks the participants if they have a theory. S1 initiates a proposition (U2). What distinguishes this sequence is not the quality of the initial suggestion but that both the researcher and at least one student tried to build on this suggestion. Throughout this discussion, the researcher does not supply knowledge but scaffolds a line of reasoning occasionally asking questions to identify possible gaps. S1 draws on knowledge of proteins in cell membranes to elaborate a model, ‘key and keyhole’ (U8). The researcher asks for

Table 7 Extract of group A's discussion of the fifth slide (cells have 'hairs')

Utterances	Student	Text	Code
1	Scientist	The scientist introduced the fifth slide, asking students to explain the mechanism of separation knowing that the neurons have hair like dendrites	
2	S4	Do you remember what dendrites are?	Q
3	S1	They're the ones that are in the final.	R
4	S5	The renal tubule	PK
5	S3	The cell body	PK
6	S1	They are those little branches	PK
7	S5	Of the renal tubule	RK
8	S3	Not even	O
9	S6	They carry the nervous. no, I don't know. I don't really remember the exact shape Either they are those that carry it to the next one or they are those that catch it from the other cell	PK
10	S1	It is the same thing, since they are joined together	R
11	S6	In fact, yes, it's the same thing	A
12	S7	Is it the one with the myelin?	Qc PK
13	S1	That's the neural axon. So the dendrites are the ones who send the neural impulse.	R PK
14	S2	They carry it, they take it.	El
15	S4	Neurotransmitters basically	PK

Table 8 Extract of group D's discussion of the fourth slide (three-dimensional representation of cells' movement)

Utterance (U)	Participant	Text	Code
1	R	Your other theory?	Q
2	S1	It has to do with cell membranes and that they have some proteins..	R IS
3	R	Yes?	R
4	S1	… that have different shapes. And when they come closer, maybe… one type might have this protein and the other might have.	El
5	S4	Another receptor you think?	Q
6	S1	Yes, it has this thing and as they come closer they click	El
7	R	And then?	Q
8	S1	And then this thing keeps happening, it's like a key and a keyhole and they click	El Ex
9	S3	And is it a chain?	Qc
10	R	And then why do they break?	Q
11	S1	Why?	Q
12	R	Why do they separate?	Qc
13	S1	Maybe these are simply not compatible with the others, so over time, they become too many of this type and too many of the other type and they just separate	Ex

clarification of the mechanism (U12), which results in S1 explicating the problem with their own suggestion (U13).

While there needs to be a basic level of background knowledge to engage, it is not the breadth or depth of content knowledge that is necessary to promote a reasonable explanation of a mechanism but the supporting dialogue in allowing the initial suggestion to be more fully explicated involving elaborations and clarifications, and in this case significant rebuttal. This exemplifies exploratory dialogue resulting in a contested explanation, one that could provide fertile ground for deeper interrogation.

Summary of Findings

Our findings relate first to dialogic structures which support knowledge building, and secondly to the ways in which prior knowledge can be drawn on to support explanation. We identified four distinct types of dialogue which helped to build knowledge: *cumulative talk* in which participants add to information with little or no critical analysis; *critical elaboration* in which critical questions and subsequent explanations can clarify participant suggestions; *problematizing suggestions* where objections are made through the use of evidence to initial suggestions; *asking questions*, which proved to be a form of explanatory talk, where rebuttals provoke explanations. On the other hand, non-constructive dialogues appeared to concern not only cases where distraction took place, but also cases where there was consensus without elaboration or justification. There were few cases of prior knowledge being used fruitfully to build explanations but where they were the group researcher had played an important role in scaffolding the discussion.

Discussion

We have highlighted sequences of dialogue which enabled evidence or knowledge to be built up so an explanation could be produced. In what follows, we first discuss the four forms of what we have called constructive dialogue that were depicted from the transcripts. Finally, we discuss the role of prior knowledge on building explanations.

Focusing on those dialogic exchanges which support knowledge construction, participants build on ideas suggested by other members of their group in order to reach consensus on the solution of the scientific problem presented by the scientist. Cumulative talk helped to build up knowledge which could later be discussed more critically and with more focused reasons. Unlike the other forms of constructive dialogues, the cumulative talk episodes contained no questions or objections.

In the case of ‘critical elaborations’, the way participants elaborated on each other’s suggestions has similarities with the features of ‘exploratory talk’ as described by Mercer et al. (2004), especially as far as it concerns respect for each other’s opinions and striving for consensus.

In our study, objections and disagreements were sometimes observed during the discussions (e.g. extracts 3 and 4), and it was these discussions that proved most fruitful in terms of deepening and diversifying explanations. From similar studies carried out in the UK (submitted for publication), we suggest that engagement in research problems offers up opportunities for disagreement and exploration of alternative suggestions. Researchers, such as Bierema et al. (2017) and Zagallo et al. (2016), found that students seldom disagreed with one another during classroom discussions. However, if students are to be prepared for open research questions in higher education then they need to speculate knowledgeably and to probe with questions or alternative suggestions (Chinn and Malhotra 2002).

Questioning was particularly useful when students worked in groups and tried to solve unknown problems. Questions led to productive discussions, helped students move forward when feeling stuck and asked for clarifications and explanations (similar conclusions about the importance of asking questions in Chinn et al. 2002; Gillies et al. 2014). In addition, students often asked elaborating questions when another student made a suggestion that was not clear; these types of questions stimulated the students to discuss their ideas in more depth.

In relation to the question of the importance of prior knowledge, in our study we observed that on occasions students could draw on topics they had studied previously and use prior experiences and knowledge in order to formulate hypotheses and suggest solutions. This is consistent with other studies of open problem-solving where students used prior knowledge to develop arguments (Rudsberg and Öhman 2015). Milbourne and Wiebe (2018) for example showed that students with deeper content knowledge were better at solving ill-structured physics problems. In another study, von Aufschnaiter et al. (2008) concluded that, in order for an argumentation activity to have an influence on students' knowledge, it must be related to students' prior knowledge.

However, evidence of the present study raises questions as to the basic level of knowledge needed to address open questions, and how students can reclaim school knowledge in discussing research problems to which school scientific knowledge cannot easily be applied (Chinn and Malhotra 2002). Indeed, where students had come across biological terms mentioned by the presenting scientist they frequently did not know how to employ that knowledge. Where they could draw on prior science knowledge, the researcher played a crucial role in prompting or supporting reasoning drawing on subject knowledge or asking qualifying questions, as seen in Table 8. While this is one example, the nature of the scaffolding suggests it is a procedure that should be encouraged.

Evidence from this study shows that prior knowledge can also hinder the ability of students to think in a creative way. The discussions, particularly during the last three slides, were often focused on what students already know about neurons, instead of analysing the new information and its relation to the problem (Table 7). In addition, students sometimes based their arguments on unrelated facts and this resulted in prior knowledge affecting the coherence of their suggestions.

School science is quite different from research science (Chinn and Malhotra 2002). For example, where research science is open, uncertain and draws on tentative knowledge, school science is often illustrative and closed. Importantly, school investigations employ changes of single variables whereas science research frequently employs multivariate changes. Students need opportunities to talk about these problems, and, even if a solution is not apparent, to at least appreciate the complexity of the task. Exploratory dialogue can move towards these aims, and help make sense of scientific concepts and communicate ideas (Ebenezer and Puvirajah 2005).

Implications

The findings of this research have three main implications. First, school students and non-specialist university students can engage with open problems in scientific research. Although problematization and probing questions were relatively rare, such tasks based on contemporary research could encourage more exploratory talk with appropriate scaffolding. Table 7, for example, demonstrates that with relatively light scaffolding from an expert, students could begin to contest and potentially deepen their explanations. In terms of bridging the gulf between school and university research-based tasks, drawing on school knowledge could begin to enlighten students as to the complex but exciting potential of scientific research.

Secondly, detailed scientific knowledge is not required for initial probing. Indeed, participants were often distracted by technical terms such as 'dendrites' introduced too early on. This may be a lesson for the authors of this paper to consider in future interventions: a not so difficult example from a less advanced area of research might prompt more patterns of constructive dialogue.

Finally, school students could begin to tackle research papers with the assistance of teachers and researchers both to gain insight into the differences between research science and school science, and to develop their argumentation skills. Teachers liaising with researchers could either discuss papers with school students or they could be simplified so that students could speculate using extant knowledge in deepening their understanding of research.

In this study, researchers enabled discussion to be initiated and to continue but could perhaps have played a more substantial role in prompting discussion of differences. There was little evidence of prior knowledge being drawn upon to substantiate alternative explanations. There is therefore scope for researchers to anticipate the suggestion of possible mechanisms, for example, the role of attractive charges or chemical signals and to further prompt participants as to what experiment they might devise to test the mechanism.

Limitations

It is important to note that our findings and implications are based on pilot research which we are now trialling with more students. It should be added that we have selected those interactions which did advance knowledge and explanatory power; a majority of exchanges were unproductive in this respect. On the other hand, this was trialled with students who had no experience of scientific research, including university students who had not studied cell biology since the end of their high school years. There were relatively few examples of knowledge building through dialogue and effective use of prior knowledge in constructing an explanation. Nonetheless, we suggest that those productive examples demonstrate distinctive forms of dialogic exchange which could provide the base for effective interventions in building knowledge through engagement in research.

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