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Teacher interventions in small group work in secondary mathematics and science lessons

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ABSTRACT

Collaborative problem solving, when students work in pairs or small groups on a curriculum-related task, has become an increasingly common feature of classroom education. This paper reports a study of a topic which has received relatively little attention: how teachers can most usefully intervene when students are working in a group, but have encountered some sort of problem. The data used comes from a large-scale interventional study of mathematics and science teaching in secondary schools in south-east England, in which interactions between teachers and students were recorded in their usual classrooms. We identify the typical problem situations which lead to teachers' interventions, and describe the different ways teachers were observed to intervene. We examine the different types of intervention, and consider how effective they are in helping group work proceed in a productive manner. Finally, we offer some conclusions about the practical implications of these findings.

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Introduction

Research suggests that collaborative activity can be effective in promoting students' learning, and group work has become increasingly common in classrooms throughout the world (Galton and Hargreaves 2009; Howe 2010; Mercer and Littleton 2007; Slavin 2009). However, while group work is potentially very productive, it commonly is not: and students often find engaging in collaborative work difficult (Baines, Blatchford, and Kutnick 2003; Galton et al. 1999; Howe and Abedin 2013). Three aspects of group work have been considered central for success. The *skill to work collaboratively* is well recognized as an important condition for productive group work (Gillies 2008; Mercer et al. 2004; Scott, Mortimer, and Aguiar 2006). Productive group work also requires *tasks* that are suitable for being tackled collaboratively (Cohen 1994; Hofmann 2008; Howe and Abedin 2013). This paper focuses on a third important condition for supporting group discussions, how teachers manage group work in their classrooms, which remains under-researched (cf. Bennett et al. 2010; Osborne et al. 2013; Webb et al. 2009). Despite a reasonable body of evidence about how students should behave for group work to be effective, there is considerable vagueness and

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uncertainty about how teachers can best support and sustain subject-based discussions in groups. And while some research suggests that groups are most likely to be productive if teachers avoid intervening (Howe 2010), there is little doubt that if teachers simply leave groups to struggle a lot of educational time will simply be wasted.

The study reported addresses these issues with regard to group-based activity in secondary science and mathematics lessons, focusing on the role of the teacher as a monitor and guide for students' collaborative activity once it is underway. This study is part of the *epiSTEMe* (Effecting Principled Improvement in STEM Education) project (Ruthven et al. forthcoming), in which a research-informed pedagogical intervention programme was created to encourage mathematics and science teachers to use more 'dialogic' strategies (Alexander 2006; Mortimer and Scott 2003). The teachers involved taught students in Year 7 (11−12 years), the first year of secondary education in the English system. At the start of the project, each class took a module involving practicing discussion skills and developing class 'ground rules' for talk (Mercer et al. 2004; Mercer and Littleton 2007). Based on a synthesis of international research on effective pedagogy in science and mathematics, the intervention also drew on the notion of using carefully crafted authentic problems to encourage students to engage more deeply with the conceptual issues in both whole-class discussions and group activity (Ruthven et al. 2011; Ruthven and Hofmann 2013; Taber et al. 2015; Howe et al. 2015).

The collaborative group work in the *epiSTEMe* pedagogic approach entails that students work together on the task as a group to reach, through discussion, a group outcome on which all members agree. Group work serves as an exploratory phase for subsequent whole-class discussion; its purpose is the emergence of multiple student-initiated ideas which can be discussed in subsequent whole-class dialogue (Ruthven, Hofmann, and Mercer 2011), hence enabling students to come up with their own ideas about the task is central.

Teachers' pedagogical interventions to support small-group work: realities and challenges

A body of evidence suggests that, for group discussion to be productive, students should *share their ideas* and *support them with reasons*, *discuss different views* and *resolve these* to achieve *group consensus* (Howe 2010; Mercer and Howe 2012; Littleton and Howe 2010; Mercer and Littleton 2007; see also Bennett et al. 2010; Kyriacou and Issitt 2008). However, this research also suggests that such characteristics of group discussions are not commonly found in classrooms, and that teachers find managing group discussions difficult. The question arises as to whether teachers' habitual ways of intervening in small-group work enable students to make better sense of a set task and/or encourage the kinds of productive dialogue which will help them gain the most from their collective thinking.

Research findings on what teachers should do to support these processes during group work are divergent. Several studies suggest that teachers should withhold queries regarding the content of the task and instead ask general questions, such as inviting contributions (Baines, Blatchford, and Chowne 2007; Blatchford et al. 2003; Myhill 2006). It is thought that teacher engagement with problem content increases dependence on the teacher and removes students' autonomy and initiative with the task (Cohen 1994b cited in Chiu 2004; cf. also Howe, Tolmie, Duchak-Tanner & Rattray 2000). Chiu (2004, 367) concludes that 'teachers who use questions to provide minimal problem content information can improve students' CL [cooperative learning] by bolstering their autonomy, initiative and interdependence'.

Other research, particularly on mathematics lessons, has found that non-content specific questions do not lead to students providing explanations (Franke et al. 2009; Henningsen and Stein 1997; Kyriacou and Issitt 2008; Meloth and Deering 1999). Henningsen and Stein (1997) and Meloth and Deering (1999) found that when teachers did not provide students with enough information, students were not able to discuss the task meaningfully. Henningsen and Stein argue that to maintain a high cognitive level in students' discussions and explaining, teachers need to model high-level performance and avoid removing the challenging aspects of the task. Webb et al. (2009) also found that one of the strongest influences on how students talk together in groups is how their teacher talks with them.

Similarly, some authors have proposed avoiding immediate *evaluation* of students' contributions, arguing that to maintain high-quality discussions in groups, teachers need to focus on promoting the development of understanding rather than just the identification of correct answers (Henningsen and Stein 1997; Kyriacou and Issitt 2008; Myhill 2006; Rojas-Drummond and Mercer 2003). On the other hand, Chiu (2004) found that when teachers evaluated students' ideas during group work, students were more likely to engage with the task than in the absence of evaluation. Chiu suggests that non-evaluative teacher interventions to a group were ineffective because they were not contingent on the group's current needs.

We suggest that these different views on what makes teacher interventions effective reflect the current limited state of understanding about these matters. Content-specific support may link with students' current needs and may help them reach a correct solution, but may come at a cost of reducing their own independent thinking and reasoning about the task. On the other hand, non-content specific feedback allows for student autonomy but may not be sufficient for helping students make progress. We suggest that teachers' interventions in small-group work need to be *contingent* on any difficulties that the students are encountering, but without inducing *dependence* on the teacher, (i.e. without removing the need for students' own collective thinking to achieve a proposed resolution). However, it is clear that we do not yet know what such interventions could look like in real mathematics and science classrooms. This is the focus and contribution of our current study.

Studies of existing classroom practice indicate that teachers' interventions during group work are usually prescriptive, focused on procedures and performance, and generate high student dependence on the teacher. Students' contributions are typically evaluated immediately; correct ideas proposed by students are accepted at face value (without seeking further justification), whereas incorrect student contributions are ignored and the thinking behind them rarely probed (Chiu 2004; Henningsen and Stein 1997; Mercer, Dawes, and Staarman 2009; Webb et al. 2009; Webb, Nemer, and Ing 2006). Webb and colleagues (2006, 109) speak of an 'entrenched culture of low-level questions and explanations' in (mathematics) classrooms. Researchers have found that getting teachers to change such established practices is difficult (Osborne et al. 2013; Webb et al. 2009, 2006). Gillies and Khan (2008) found that professional development training needed not only offer new strategies for intervention, but also to raise teachers' awareness of the purposes of group work. We suggest that it may be useful to take one step back from trying to change teachers' behaviour, and consider *why* they may intervene in group work in such ways.

Understanding the sociocultural norms and goals of classroom discussions

The ultimate aim of our analysis is to identify ways in which teachers can most usefully intervene in group work in mathematics and science classrooms, so that this can inform teachers' actions and teacher education. To present such different ways as simply alternatives which teachers could choose on any occasion would be naïve, and would ignore the practical reasons why teachers develop and maintain some of the interactional strategies that they do. We therefore need to examine the kinds of difficulties teachers may have in abandoning habitual strategies, and the culture within which those are embedded, which may make the take-up of new strategies difficult, or even stressful. We will argue that any proposals for change must take account of the temporal, conversational and activity structure of classroom life. To illustrate these aspects of the use of spoken language in classrooms, we will draw on theoretical approaches to education which recognize the role of language and sociocultural practice in learning.

Research on classroom interaction has established how classrooms are particular sociocultural settings, with their own norms and rules which are common knowledge to all participants (Edwards and Mercer 1987/2013). These norms inform and shape teachers' existing practice in ways that can make the take up of new pedagogic strategies difficult. For example, research has illustrated how in classroom interactions, both teachers and students expect that teachers offer evaluative feedback on students' contributions. Such normative expectations are not simply 'bad habitual responses' of the teachers, but criteria for actions perceived as 'appropriate' by all participants in those cultural situations (Edwards and Mercer 1987/2013; McHoul 1990; Sinclair and Coulthard 1975). Such expectations cannot be simply ignored if participants are to remain able and motivated to take part. Such implicit contextual frameworks are often quite well established, and so they can make it difficult to change the ways teachers and students interact, even if there are good educational reasons for seeking such changes (Hofmann 2008; Rainio and Hofmann 2015).

It is for these reasons we argue that researchers need to pay attention to what the participants in a social practice are trying to *do* through their interactions (Daniels 2004; Mercer 1995; Hofmann 2008). Research suggests that teachers actively monitor groups and decide when to intervene (Chiu 2004), and we argue that understanding these decisions better would be helpful for considering the possibility of change. Culturally and historically formed practices, including classroom teaching, are motivated by the 'problem spaces' at which we oriented our actions within those practices (Edwards 2010). What we are suggesting is that any intervention which is to have a possibility of changing such established practices must take into account what the participants are trying to get done, what problems they are trying to work on and improve.

Research questions

Our analysis of teacher interventions in small-group work on the *epiSTEMe* mathematics and science problems addresses the following research questions:

(1) In what kinds of situations do teachers intervene in groups, and why do they do so?
(2) What strategies did the teachers we observed in the *epiSTEMe* project use when intervening in group work?
(3) In what ways and to what extent are teachers' intervention strategies contingent on students' current understandings/discussion and what scope do they offer for enabling students' own thinking and ideas?
(4) What evidence might be available to a teacher, during or after an intervention, about the effects of any strategies on students' behaviour?

Data and methods

The *epiSTEMe* intervention programme was designed to enable teachers of mathematics and science in English secondary schools make more effective use of dialogue in teaching their subjects in the context of rich tasks, and discussed and piloted with a group of participating teacher collaborators. The content of the intervention programme has been described in detail elsewhere (Ruthven et al. 2011), and such detail is not directly relevant to our concerns here. In summary, the materials consisted of four topic modules each containing a series of fully-developed lessons, inclusive of projection slides, teaching notes and student booklets, with carefully crafted activities for small-group and whole-class discussion. The group activities were designed to draw out differences of perspective relevant to the topic-related problem among members of a group, which could then be debated in the pursuit of an agreed solution. The aim was to get students thinking about the topic, bring out their thinking and enable the emergence of multiple common ideas and misunderstanding about the topic to be discussed in a subsequent whole-class dialogic plenary (see Ruthven and Hofmann 2013). The intervention teachers all received the materials and two days of professional development by the *epiSTEMe* team. The professional development provided to the participating teachers as well as the teaching materials for the project included specific suggestions for ways to guide and prompt students' discussions (drawing on research such as that described in Mercer and Littleton 2007; Galton and Hargreaves 2009; Howe 2010). It was made clear to participating teachers that an important aspect of their role in relation to such group work was to encourage students to use talk effectively for collaborative problem-solving (Ruthven, Hofmann, and Mercer 2011).

We observed 10 mathematics and 2 science teachers from the pilot and main intervention phases of the project, distributed across 8 schools. This yielded audio and video data of lessons (approximately 60 min each, 18 hours in total), as well as observation notes made in-situ by the first author. Descriptive summaries were first constructed of each lesson based on the field-notes and recordings. The analysis focused just on those 'episodes' in lessons when a teacher joined a group, and we define an episode as the total time the teacher spent with a group on any one occasion.

The analysis identified a total of a 104 episodes of teacher visits to small groups totalling over three hours of recorded data, with the average duration of a teacher intervention in a group around 2 min. Sixty-nine episodes found to contain interactive data were transcribed and analysed for their turn-by-turn interactions with the aim of identifying the specific interactive strategies used by teachers and their apparent communicative consequences during the teacher's visit. Each interactive move was compared to preceding and subsequent interactive moves, and each episode was repeatedly compared to other episodes in the same overall category and to other categories, including deviant cases, until there was sufficient evidence that a category was both robust and distinctive enough. The episodes were also analysed for the different 'problem situations' that they may have posed for the teacher. While the bulk of the analysis was conducted by the first author, for reliability and validity of the coding, both authors separately coded parts of the data set and compared results. Disagreements were resolved by discussion, and the refined categories re-applied across the data-set. Only strategies used at least by two teachers were included to ensure the reported strategies are not simply part of an individual teacher's personal style and repertoire. In fact, each discussed strategy was used by at least 5 different teachers, in at least 13 episodes.

Results

We will discuss and illustrate our findings through presenting two whole episodes (one from mathematics, one from science) as well as some further brief examples.

What kinds of situations arising during group work provoke teachers to intervene?

One of our aims was to identify the kinds of problematic group situations arising in the observed classrooms that provoked teachers to make a significant intervention. We observed that, on several occasions, the teachers joined a group just to check that the group was working, or to find out whether they had finished. No further interaction then ensued, and so such interactions are not included in our analysis. In 69 episodes, more prolonged interaction between the teacher and student took place. We closely examined and compared the starting situations in these episodes which the teacher faced upon entering the group. Our analysis suggests that these episodes fell into three types of situations in which a group was proposing

- no ideas (illustrated by Example 4 below),
- an incorrect idea (Example 3) and
- a correct idea or solution (Example 2).

We suggest that it is worth noting how these different starting situations, as identified by our analysis of the discourse, relate to those identified by our participating teachers in their informal comments about implementing group work in the classroom.

We compared this analysis with comments from our participating teachers, who also identified broadly the three same categories. However, the teachers' conceptions of what was 'problematic' about these situations differed from ours. *Students not proposing ideas* was related by the teachers to the need to get the students working, while for us it was primarily a challenge of getting them thinking. *Students proposing a correct idea or solution* was typically perceived as problematic by teachers if it happened early during group work, because this would mean the group had nothing left to do while other groups worked on. Teachers did not raise our concern, which was whether this might mean that not everyone in the group understood *why* an idea was correct. Whereas *students proposing incorrect ideas or answers* was typically perceived by teachers as a problem requiring the teacher's active and immediate help (one of the teachers said: '*It is not my job to make* *students discuss incorrect ideas, it is my job to help them get it right*'). In our view, on the other hand, the discussion of all relevant (even if incorrect) student ideas might be beneficial for the development of their understanding. The teachers' comments are in accord with prior research findings about mathematics and science teaching (Chiu 2004; Howe et al. 2000), and illustrate the kinds of problems teachers think their intervention strategies are expected to address. We will return to these matters in discussing our results.

All observed interactions were initiated by the teachers in two broad ways – a 'closed' way and a relatively more 'open' way. In 13 episodes (involving three different teachers), the teacher immediately began leading the students through the correct procedure for solving the problem. However, in 54 episodes, the teacher, at least initially, began a more open discussion about the task/solution process and invited students to contribute to it. Given our discussion about typical teacher responses to small-group work revealed by previous studies, this makes our data-set worthy of closer examination. (In the two remaining episodes, the teachers commented on an issue not related to the task, such as homework.)

What strategies did the intervention teachers in our project use when intervening in group work?

Authoritative strategies

In some episodes, the teacher initiated the interaction by *taking the lead in the solution process*. In some episodes, the teacher simply accepted a correct answer from a student at face value with no further probing, or led them through every step of the solution procedure, without exploring students' understanding.

Example 1
[*A couple are expecting their first baby. Both parents have a mixed pairing of e and E alleles. How likely is their baby to have this same pairing?*]
A1. T [joins the group]: What happens to the baby? What can the baby get?
A2. S(1): Either get a double e, a big capital E.
A3. T: So how many things can happen?
A4. S(1): Three
A5. S(2): Out of four?
A6. T: How many things can happen?
A7. S(1): Four
A8. S(2): No, three.
A9. T: *Four* [with emphasis]. Right.
[Probability_HS]

The sequence in Example 1 describes a group work situation in which two students each suggest a different answer, which represent the correct (A7) and an incorrect (A4, A8) answer respectively. The teacher ignores the incorrect answer (A6) and accepts the correct answer at face value (A9) without exploring students' thinking behind their different suggestions, thereby also closing down an opportunity for discussion. The teacher's intervention strategy maintains high teacher dependence during the search for a solution. The teacher also ignores two students' apparent misunderstanding (A4, A8). The teacher regulates both the form and content of the talk and does not invite students to actively think about the task: rather, the task is constructed as one of simply speaking the correct answers.

However, some of the interactions the teachers initiate with students who seem to be 'stuck' involve more engagement with the task content and students' thinking, even if the teacher maintains a regulative role over both form and content of talk. In Example 2, students express uncertainty but nonetheless present a correct answer ('statement R is incorrect') on Line B2.

Example 2
[*Dice probability statements: Statement R: "Because anything could happen, it's impossible to know the chance of a team getting a 6"*]
B1. T: Yes, lads.
B2. S: We're not sure, but we… R's definitely not true.
B3. T: What's that, R's definitely not true, why?
B4. S1: Because it's not impossible.
B5. T: It's not impossible to tell, you can tell, can't you.
B6. S1: Yeah.
B7. T: What's the odds on me getting a six?
B8. S1: One in six.
B9. S2: Unlikely.
B10. A10. T: One in six. I prefer numbers they're better than unlikely. Let's go back to the first one?
[Probability_ FN]

In this interaction, the teacher repeats the answer offered by a student and asks the students to provide an explanation (B3). One student provides a partial correct answer (B4) which the teacher confirms as correct and asks for the missing information (B5, B7). Student 1 provides an answer (B8) which the teacher confirms as correct (B10). Another student provides an incorrect answer ('unlikely', B9) which the teacher ignores (B10), and moves on. In this episode, as in Example 1, the teacher still controls the structure and content of the talk. He does, however, probe the students' responses in a way that can be described as *contingent* (that is, it takes account of the disparity of views offered by the group members). Nevertheless, the regulation of the problem-solving process remains firmly in the hands of the teacher.

Initiating strategies

However, in the majority of the episodes the teachers did not take an immediate, authoritative lead in the solution process; and it is those episodes that we will discuss in the remainder of this section. We will first deal with how teachers *initiate* interactions with groups and then look at how they subsequently *interact* with students. We suggest those are core moments, pedagogically, wherein teachers have to make decisions about what to do, and in which the scope of the potential subsequent interaction is defined. We will present two longer episodes (Examples 3 and 4) and then discuss the strategies used by teachers in these episodes and across the data-set. In these episodes, the teachers do not immediately take over the problem-solving. Instead, they initiate the interaction with the group by using one or more of the following opening strategies:

(1) inviting students to speak (Example 3);
(2) listening silently to the discussion (Example 3);
(3) making reference to the 'ground rules' of the activity (Example 4); and
(4) focusing students on the task (Example 4).

Example 3
[*TASK: Why does a flat piece of plasticine sink but formed as a boat it floats?*]
C1. T: Go on, go on, what were you going to say?
C2. S1: I thought that with a piece of paper, you know, that when it's like this [shows with a paper that is flat] when it's in the water (it's pushing it all?) but when it's like this together..-
C3. S2: -What she is trying to say is like gravity, thrust.
C4. S(): I thought, right, that when something is flat it's like lighter, but when something is like thicker, it's like..-
C5. S2: -Heavier.
C6. T: Is that right?
C7. [*Students talking over each other*.]
C8. T: So can I just pick on what you said and what you guys said, you said that when something's spread out more, it's lighter than when you scrunch it all up.
C9. S: Yeah.
C10. T: Who thinks that's, that's right?
C11. *[Several of the students nodding: 'Yeah'.]*
C12. S2: It's because it all comes together and obviously if it's not together then it's not as *heavy*. Like there is not as much weight on one thing.
C13. [*More discussion ensues, T listens, then intervenes*.]
C14. T: Can I ask a question? Does the weight of this bit of paper change if I've got it flat like that or scrunched up?
C15. S: Not really, not really.
C16. S: Yeah..-
C17. T: [If I put it on a pair of scales or a balance, would it change?
C18. S: It could.
C19. S: I don't think so.
C20. T: It could *[repeating student answer; then to the student]* **You don't think so?**
[*T listens to a few more comments, then praises students for 'good thinking' and asks them to come up with a group agreement, leaves*.]
[Forces_CC]

In Example 3, it can be seen that the teacher invites the students to speak and listens silently and intently over several student turns while the students share their ideas and thinking at quite some length, reporting on a discussion they have had. In Example 4 (below), the students are stuck and initially not making any contributions. The teacher begins by making a general reference to one of the 'ground rules' that have been established in a previous lesson, that 'students are expected to decide on a shared answer'. After the teacher focuses the students on, and clarifies, their task, it can be seen that they go on to contribute relevant (if initially mathematically incorrect) ideas to the discussion.

Example 4
[*TASK: Trial results of a Roman Knucklebone game, with 4 different landing positions. What is the probability of each position?*]
D1. T: What have you decided on this table?
D2. S: Nothing.
D3. S: That I'm stuck.
D4. T: You're stuck. What is it you're trying to find out?
D5. S: I have no idea.
D6. S: Everything.
D7. T: What did I ask you to work out?
D8. S: I don't know, because I forgot.

D9. T: Okay. I asked you to work out the chance of that knucklebone landing on each of those four positions.
D10. S: 1 in…
D11. T: Yeah, 1 in something, or…
D12. S: 1 in…
D13. S: 4.
D14. S: … 4.
D15. T: Right. If it was 1 in 4, would they all be 1 in 4?
D16. S: Yeah.
D17. S: Yeah, because you can get one…
D18. *[Overtalking]*
D19. S: Can I just say, the knucklebone isn't exactly equal.
D20. S: It's 1 in…
D21. T: What did Jasmine just say?
D22. S: It's not equal.
D23. T: Sorry, explain what you mean.
D24. S: It's not equal.
D25. S: Those other sides aren't equal.
D26. T: So what does she mean then?
D27. S: That it's not…
D28. S: When you roll it, you can't always get the same thing.
D29. T: Yeah, so is one of them more likely than the other?
D30. S: Probably.
D31. S: If it's bigger.
D32. T: So is 1 in 4 a good answer for all of them?
D33. S: No.
D34. T: No. Can you come up with a better answer?
D35. S: What can we come up with?
D36. **T: Good question there.** [*T leaves group*.]
[Probability_IB]

There are many examples of use of such strategies across different lessons and teachers in our data. The teacher's reference to established ground rules in Example 4 is particularly interesting because it shows how a teacher can encourage a group to think about they might most productively interact to solve the problem. Prior research has shown that by establishing such rules, a teacher can encourage students to adopt ways of regulating their activity to make group discussion most productive (Mercer et al. 2004; Mercer and Littleton 2007). Other examples of references to ground rules in our data are:

- asking students to consider all opinions within the group

[*'Read a bubble out and then have a chat about it and see whether or not altogether you all agree or disagree.'*]

- asking students to try to reach group consensus

[*'Okay, you all agree B, do you?'*; *'What have you decided on this table?'*]

- asking or encouraging students to share any ideas they may have

[*'Who's got any ideas at all?'*; *'You don't understand, who understands?'; 'Anyone want to help your team member?']*

- encouraging the students to go on speaking
[*'Go on, what were you going to say?'*]

Listening intently to what students say without immediately responding is also a way teachers can encourage students' discussions, illustrated on Lines C2–C5 in Example 3. Sometimes, teachers emphasize that their silence is not meant to imply criticism: *'I'm just listening'*. Or teachers may focus students on the task at hand by reading the task out loud or asking students to read it out. But they also use more active strategies of focusing students on the task, such as asking students to explain the task, as in D4 and D7 in Example 4. If students say they do not understand, the teachers sometimes ask what students do not understand (*'Tell me what it is you don't understand?'*).

Continuing interactive strategies

In the episodes in which teachers continue to encourage student discussion of ideas, we have observed four core strategies which teachers employed once they have begun interacting with a group in ways which do not involve closing down the discussion:

(1) repeating relevant ideas expressed by students;
(2) probing and exploring students' understandings;
(3) encouraging students to compare and test ideas; and
(4) identifying resources for thinking.

An example of a teacher repeating relevant ideas expressed by students is illustrated in Line C8 in Example 3, thus highlighting their relevance to the discussion (not necessarily indicating their correctness). Teachers also sometimes asked students to repeat what another group member had said – as illustrated on Line D21 in Example 4. They also sometimes reformulated what a student had said, so as to clarify it:

Example 5
[*Dice probability discussion statements: "Because Team B is overdue a 6, they are more likely than Team A to throw a 6 in this last round."*]
E1. S: Yeah, but it depends what they get before. You don't know that they will all get like...
E2. T: See, what you're saying is it depends on what they've thrown the dice before as to what they're going to get next.
[Probability_IE]

Such strategies have long been recognized as common in whole-class interactions (Edwards and Mercer 1987/2013). Moreover, teachers sometimes probed and explored students' understandings behind the ideas and answers they offered. For example:

Why do you think that?
Can you explain what you mean?
How did you arrive at that conclusion?
Convince me!
Can you tell me why you aren't convinced of what your group is suggesting?
What is wrong with the alternative answer?

In Example 4, this is illustrated in Line D23 when the teacher asks the student to explain her thinking.

The teachers in the data also encouraged the students to compare and test ideas themselves, for example, by asking for others' perspectives and by asking others to comment on the idea of a group member, or by asking a student to explain an idea proposed by a group member, as in Lines D21–D26 in Example 4. This can help students notice that they have different ideas that could usefully be discussed and compared. This strategy is specifically illustrated in Example 6.

Example 6
F1. T: Alec seems to think, when you need to, as a group we need to come up with an agreement, yeah? So Alec thinks one thing, Charlie thinks another, so you two need to, that's it's 50/50. So you agree with it- [students start talking over the teacher].
[Probability_EB]

Finally, another strategy identified is to make available to students additional relevant resources for thinking about the problem. This can mean providing students with additional mathematical or scientific information relevant to the task, without taking them through the solution strategy (such as 'the probability of 1 means certain'). They may direct students to consider a specific resource e.g. *'Do have any information that might help you?'* or *'So what does the table mean? Why is the table there? Is that helping us at all?'*. For example, in Example 7 in lines G1 and G3, a teacher refers to a mathematical tool that the students have encountered earlier in another task which could help them solve the current problem.

Example 7
[QUESTION: Both parents have a mixed pairing of **e** and **E** alleles. *How likely is their baby to have this same pairing?*]
G1. T: Is there a way you could work out the different combinations of genes that you could get. You know when we did the-
G2. S(M): -Table.
G3. T: Table. Yes. When we had heads and tails.
[Probability_IB]

How may the strategies support students' thinking and how may this become visible for the teacher?

The teachers in our study used a variety of strategies to encourage students to express and discuss their ideas. Table 1 lists the types of problem situations which teachers were observed to encounter when joining a group of students, and also shows which interactive strategies teachers were observed to use in dealing with them.

Inviting students to speak (Examples 3 and 4) is a general, non-content specific strategy which prior research suggests is insufficient in encouraging a focus on understanding and explaining (Franke et al. 2009; Henningsen and Stein 1997; Kyriacou and Issitt 2008). However, it is an easy way of initiating interactions with the group that avoids the teacher immediately taking over the task. Furthermore, the ways it was done by some of the teachers we observed enabled them to highlight the importance of student-initiated ideas. It also gave the teacher the opportunity to find out what difficulties the students were facing, and enabled subsequent contingent responses (Examples 3 and 4). If students are not proposing any ideas, the strategy of asking them if they understand what they have been asked to do (Example 4)

Table 1. Types of problem situations in group work, and interactive strategies which teachers were observed to use in dealing with them.

	'Problem' situation		
Interactive strategy	Students are not proposing ideas	Students are proposing incorrect ideas	Students are proposing correct ideas
Making reference to ground rules	X		X
Focusing on task	X		
Inviting to speak	X	X	
Active listening		X	
Repeating relevant ideas expressed by students		X	X
Probing and exploring students' understandings		X	X
Encouraging students to compare and test ideas		X	X
Identifying resources for thinking	X	X	

focuses their attention on the content of the task and allows the teacher to be helpful, without being prescriptive.

The strategy of active listening (Example 3) can be considered contingent in that it does not disrupt students' current interactions and models the 'ground rule' of giving proper consideration to other people's ideas (Mercer and Littleton 2007; cf. Kyriacou and Issitt 2008; Myhill 2006). We have also observed teachers encouraging a group to strive for agreement in Example 3 (C14−C20). In response to such non-authoritative initiating strategies, students may subsequently elaborate their ideas at some length (Example 3), even if they were initially not discussing the task (Example 4). This may help a teacher recognize that such strategies are a good alternative to simply taking over the problem-solving process.

Repeating ideas expressed by students (Example 3 C8; Example 4 D11; Example 5), probing students' understandings by asking them to explain further (Example 4 D23) and asking students themselves to compare and test ideas (Example 6) can function as contingent strategies that do not take over the authority from the students: they link with what students are currently discussing and suggesting while focusing students on understanding. Proposing resources for thinking (Example 7) can offer help that is targeted at students' current needs without evaluating their ideas or providing answers. It also guides students towards the useful heuristic strategy of looking for suitable resources to help their mathematical thinking in any situation.

Discussion and conclusions

Our study illustrates the range of ways teachers can intervene in students' group discussions in mathematics and science classrooms. Research on group work suggests that it is most productive for learning and the development of understanding if teachers 'model' effective ways of using talk to solve problems collectively, agree on suitable 'ground rules' for discussion with students, regularly remind students of those rules and (having set suitable tasks) allow students enough time to engage in thoughtful discussion (Howe 2010; Mercer and Littleton 2007; Slavin 2009). We have shown that some of the strategies used by the teachers we observed are compatible with those principles, while others are not. We also showed that teachers can intervene in group work in ways which are contingent on the difficulties students are facing at that point (which prior research has suggested is useful for promoting learning: Chiu 2004), without simply authoritatively providing or confirming a solution. One concern expressed to us by teachers is that a group which is 'stuck' on a problem may simply waste time if they are left to their own devices. Our analysis shows that some non-authoritative and non-evaluative strategies often are sufficient to help such groups to start proposing ideas and (re-)engage with the task. While we have no evidence from this study that some strategies promoted better learning outcomes than others, it seems reasonable to infer that those which encourage students to co-regulate their group work and bolster their 'autonomy, initiative, and interdependence' (Chiu 2004, 347) are of pedagogical value.

In the early part of this paper, we also discussed the finding from prior research that teachers' habitual responses to classroom situations are difficult to change. Our perspective on this issue is that any proposal for changing teachers' current classroom practice needs to be embedded in an understanding of what motivates that practice, what purposes it serves. We drew on sociocultural and linguistic research to justify this view. We see practitioners' actions as oriented towards concrete and specific problems of practice (cf. Ruthven 2005). Teachers, like people in many demanding occupations, have to develop ways of dealing with problems as they arise. We have illustrated and applied this idea by framing our analysis of strategies by paying attention to what teachers themselves view as problems in group work, which any suggested new strategies must be capable of addressing. We have shown that some non-authoritative strategies can deal effectively with those situations that teachers see as problematic: supporting groups being 'stuck' or pursuing a wrong idea, or meaningfully occupying students who think they have 'got' the right answer straightaway. Earlier, we also reported that the reasons why teachers saw such situations as problematic were not the same as the reasons we had as researchers. Nevertheless, most teachers, we believe, would also welcome effective ways of getting students to re-engage with a task, to think more critically about ideas, to develop their own problem-solving abilities and not merely get the correct answer quickly but also be able to justify it. If we can show teachers that some of the non-authoritative interventional strategies identified in our study – as used by practising teachers like themselves, not merely being advocated by researchers – can serve to alleviate those kinds of problems and achieve other worthwhile educational aims, then they are likely to be seen as welcome additions to their repertoire of strategies. While different educational cultures prioritize talk in different ways (Alexander 2001), reflecting upon the possibilities and local impact of changing established patterns of talk can be beneficial in any setting.

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References

Alexander, R.J. 2001. *Culture and Pedagogy: International Comparisons in Primary Education*. Oxford: Blackwell.

Alexander, R.J. 2006. *Towards Dialogic Teaching: Rethinking Classroom Talk*. Cambridge: Dialogos.

Baines, E., P. Blatchford, and A. Chowne. 2007. "Improving the Effectiveness of Collaborative Group Work in Primary Schools: Effects on Science Attainment." *British Educational Research Journal* 33 (5): 663–680.

Baines, E., P. Blatchford, and P. Kutnick. 2003. "Changes in Grouping Practices Over Primary and Secondary School." *International Journal of Educational Research* 39 (1): 9–34.

Bennett, J., S. Hogarth, F. Lubben, B. Campbell, and A. Robinson. 2010. "Talking Science: The Research Evidence on the Use of Small Group Discussions in Science Teaching." *International Journal of Science Education* 32 (1): 69–95.

Blatchford, P., P. Kutnick, E. Baines, and M. Galton. 2003. "Toward a Social Pedagogy of Classroom Group Work." *International Journal of Educational Research* 39 (1–2): 153–172.

Chiu, M.M. 2004. "Adapting Teacher Interventions to Student Needs During Cooperative Learning: How to Improve Student Problem Solving and Time On-Task." *American Educational Research Journal* 41 (2): 365–399.

Cohen, E.G. 1994. "Restructuring the Classroom: Conditions for Productive Small Groups." *Review of Educational Research* 64 (1): 1–35.

Daniels, H. 2004. "Activity Theory, Discourse and Bernstein." *Educational Review* 56 (2): 121–132.

Edwards, A. 2010. *Being an Expert Professional Practitioner: The Relational Turn in Expertise*. Vol. 3. Springer Science & Business Media.

Edwards, D., and N. Mercer. 1987. *Common Knowledge: The Development of Understanding in the Classroom*. London: Routledge.

Franke, M.L., N.M. Webb, A.G. Chan, M. Ing, D. Freund, and D. Battey. 2009. "Teacher Questioning to Elicit Students' Mathematical Thinking in Elementary School Classrooms." *Journal of Teacher Education* 60 (4): 380–392.

Galton, M., and L. Hargreaves. 2009. "Group Work: Still a Neglected Art?" *Cambridge Journal of Education* 39 (1): 1–6.

Galton, M., L. Hargreaves, C. Comber, D. Wall, and T. Pell. 1999. *Inside the Primary Classroom: 20 Years On*. London: Routledge.

Gillies, R.M. 2008. "The Effects of Cooperative Learning on Junior High School Students' Behaviours, Discourse and Learning During a Science-Based Learning Activity." *School Psychology International* 29 (3): 328–347.

Gillies, R.M., and A. Khan. 2008. "The Effects of Teacher Discourse on Students' Discourse, Problem-Solving and Reasoning During Cooperative Learning." *International Journal of Educational Research* 47 (6): 323–340.

Henningsen, M., and M.K. Stein. 1997. "Mathematical Tasks and Student Cognition: Classroom-Based Factors that Support and Inhibit High-Level Mathematical Thinking and Reasoning." *Journal for Research in Mathematics Education* 28: 524–549.

Hofmann, R. 2008. "Ownership in Learning: A Sociocultural Perspective on Pupil Engagement, Collaboration and Agency in the Classroom." Unpublished PhD diss., University of Cambridge.

Howe, C. 2010. *Peer Groups and Children's Development*. Oxford: Wiley-Blackwell.

Howe, C., and M. Abedin. 2013. "Classroom Dialogue: A Systematic Review Across Four Decades of Research." *Cambridge Journal of Education* 43 (3): 325–356.

Howe, C., S. Luthman, K. Ruthven, N. Mercer, R. Hofmann, S. Ilie, and P. Guardia. 2015. "Rational Number and Proportional Reasoning in Early Secondary School: Towards Principled Improvement in Mathematics." *Research in Mathematics Education* 17 (1): 38–56.

Howe, C., A. Tolmie, V. Duchak-Tanner, and C. Rattray. 2000. “Hypothesis Testing in Science: Group Consensus and the Acquisition of Conceptual and Procedural Knowledge.” *Learning and Instruction* 10 (4): 361–391.

Kyriacou, C., and J. Issitt. 2008. *What Characterises Effective Teacher-Initiated Teacher-Pupil Dialogue to Promote Conceptual Understanding in Mathematics Lessons in England in Key Stages 2 and 3: A Systematic Review*. London: EPPI-Centre, Social Science Research Unit, Institute of Education, University of London.

Littleton, K., and C. Howe. 2010. *Educational Dialogues: Understanding and Promoting Productive Interaction*. London: Routledge.

McHoul, A. 1990. “The Organization of Repair in Classroom Talk.” *Language in Society* 19 (3): 349–377.

Meloth, M.S., and P.D. Deering. 1999. “The Role of the Teacher in Promoting Cognitive Processing During Collaborative Learning.” In *Cognitive Perspectives on Peer Learning*, edited by A. O’Donnell and A. King, 235–255. Manwah, NJ: Lawrence Erlbaum.

Mercer, N. 1995. *The Guided Construction of Knowledge: Talk Amongst Teachers and Learners*. Clevedon: Multilingual Matters.

Mercer, N., L. Dawes, and J.K. Staarman. 2009. “Dialogic Teaching in the Primary Science Classroom.” *Language and Education* 23 (4): 353–369.

Mercer, N., L. Dawes, R. Wegerif, and C. Sams. 2004. “Reasoning as a Scientist: Ways of Helping Children to Use Language to Learn Science.” *British Educational Research Journal* 30 (3): 359–377.

Mercer, N., and C. Howe. 2012. “Explaining the Dialogic Processes of Teaching and Learning: The Value and Potential of Sociocultural Theory.” *Learning, Culture and Social Interaction* 1 (1): 12–21.

Mercer, N., and K. Littleton. 2007. *Dialogue and the Development of Children’s Thinking: A Sociocultural Approach*. London: Routledge.

Mortimer, E.F., and P.H. Scott. 2003. *Meaning Making in Science Classrooms*. Milton Keynes: Open University Press.

Myhill, D. 2006. “Talk, Talk, Talk: Teaching and Learning in Whole Class Discourse.” *Research Papers in Education* 21 (1): 19–41.

Osborne, J., S. Simon, A. Christodoulou, C. Howell-Richardson, and K. Richardson. 2013. “Learning to Argue: A Study of Four Schools and Their Attempt to Develop the Use of Argumentation as a Common Instructional Practice and its Impact on Students.” *Journal of Research in Science Teaching* 50 (3): 315–347.

Rainio, A.P., and R. Hofmann. 2015. “Transformations in Teachers’ Discourse About Their Students During a School-Led Pedagogic Intervention.” *The European Journal of Social and Behavioural Sciences* 13 (2): 1815–1829.

Rojas-Drummond, S., and N. Mercer. 2003. “Scaffolding the Development of Effective Collaboration and Learning.” *International Journal of Educational Research* 39 (1): 99–111.

Ruthven, K. 2005. “Improving the Development and Warranting of Good Practice in Teaching.” *Cambridge Journal of Education* 35 (3): 407–426.

Ruthven, K., and R. Hofmann. 2013. “Chance by Design: Devising an Introductory Probability Module for Implementation at Scale in English Early-Secondary Education.” *ZDM* 45 (3): 409–423.

Ruthven, K., R. Hofmann, C. Howe, S. Luthman, N. Mercer, and K. Taber. 2011. “The epiSTEMe Pedagogical Approach: Essentials, Rationales and Challenges.” *Proceedings of the British Society for Research into Learning Mathematics* 31 (2): 131–136.

Ruthven, K., R. Hofmann, and N. Mercer. 2011. “A Dialogic Approach to Plenary Problem Synthesis.” In *Proceedings of the 35th Conference of the International Group for the Psychology of Mathematics Education*, edited by B. Ubuz, Vol. 4, 81–88. Ankara: PME.

Ruthven, K., N. Mercer, K. Taber, P. Guardia, R. Hofmann, S. Ilie, S. Luthman & F. Riga (forthcoming). “A research-informed dialogic-teaching approach to early secondary-school mathematics and science: the pedagogical design and field trial of the epiSTEMe intervention.” *Research Papers in Education*.

Scott, P.H., E.F. Mortimer, and O.G. Aguiar. 2006. "The Tension Between Authoritative and Dialogic Discourse: A Fundamental Characteristic of Meaning Making Interactions in High School Science Lessons." *Science Education* 90 (4): 605−631.

Sinclair, J.M., and M. Coulthard. 1975. *Towards an Analysis of Discourse: The English Used by Teachers and Pupils*. London: Oxford University Press.

Slavin, R.E. 2009. "Cooperative Learning." In *International Encyclopedia of Education*, edited by G. McCulloch and D. Crook, 161−178. Abington: Routledge.

Taber, K., K. Ruthven, C. Howe, N. Mercer, F. Riga, R. Hofmann, and S. Luthman. 2015. "Developing a Research-Informed Teaching Module for Learning About Electrical Circuits at Lower Secondary School Level: Supporting Personal Learning About Science and the Nature of Science." In *Cases on Research-Based Teaching Methods in Science Education*, edited by E. de Silva, 122−156. Hershey, PA: IGI Global.

Webb, N.M., M.L. Franke, T. De, A.G. Chan, D. Freund, P. Shein, and D.K. Melkonian. 2009. " 'Explain to Your Partner': Teachers' Instructional Practices and Students' Dialogue in Small Groups." *Cambridge Journal of Education* 39 (1): 49−70.

Webb, N.M., K.M. Nemer, and M. Ing. 2006. "Small-Group Reflections: Parallels Between Teacher Discourse and Student Behavior in Peer-Directed Groups." *The Journal of the Learning Sciences* 15 (1): 63−119.