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Inquiry and groups: student interactions in cooperative inquiry-based science

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ABSTRACT

Science education research has recommended cooperative inquiry based science in the primary science context for more than two decades but after more than 20 years, student achievement in science has not substantially improved. This study, through direct observation and analysis, investigated content-related student interactions in an authentic inquiry based primary science class setting. Thirty-one upper primary students were videotaped working in cooperative inquiry based science activities. Cooperative talk and negotiation of the science content was analysed to identify any high-level group interactions. The data show that while all groups have incidences of high-level content-related group interactions, the frequency and duration of these interactions were limited. No specific pattern of preceding events was identified and no episodes of high-level content-related group interactions were immediately preceded by the teacher's interactions with the groups. This in situ study demonstrated that even without any kind of scaffolding, specific skills in knowing how to implement cooperative inquiry based science, high-level content-related group interactions did occur very briefly. Support for teachers to develop their knowledge and skills in facilitating cooperative inquiry based science learning is warranted to ensure that high-level content-related group interactions and the associated conceptual learning are not left to chance in science classrooms.

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Inquiry-based science learning has been endorsed as a more effective and preferred method of delivering science education in the primary (elementary) environment during the last 50 years, and in the last 20 years has gained widespread acceptance in the educational community (McConney, Oliver, Woods-McConney, Schibeci, & Maor, 2014; Minner, Levy, & Century, 2010; Shymansky, Hedges & Woodworth, 1990). Inquiry-based science learning typically involves cooperative (small) groups and is seen as an authentic representation of science that facilitates high levels of student science understanding in an environment that involves context, exploration, explanation and application (Australian Curriculum and Assessment Reporting Authority, n.d.), while encouraging students to use evidence, logic and imagination to make sense of the world

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around them (Newman et al., 2004). Inquiry-based science learning can be referred to as a combination of the more traditional science processes along with scientific knowledge and reasoning, and critical thinking to develop scientific literacy (Lederman, Lederman, & Antink, 2013).

Cooperative groups in inquiry-based science learning require students to work together with an approach that models what scientists actually do as they work to examine problems, ask questions, challenge perspectives and collaborate to reach shared understandings (Duschl & Shouse, 2007; Gillies, Nichols, Burgh, & Haynes, 2014). This is especially important, since research on cooperative group work has shown that working and learning in groups improves achievement, motivation, social interactions and problem-solving in science (Acar & Tarhan, 2008; Cohen, 1994; Qin, Johnson, & Johnson, 1995). The strength of cooperative group work lies in the interactive and learner-centred nature of the learning environment. Intense, mutual exchanges of ideas are valued, and it can be argued, a main goal of cooperative group work (Chi, 2009). When students in cooperative groups are engaged in high-level discourse, the groups can be considered productive in terms of conceptual learning and higher order thinking (Cohen, 1994; Gillies et al., 2014).

The strengths of cooperative inquiry-based science would lead one to believe that student outcomes would increase. However, after 20 years of implementing cooperative inquiry-based science, student achievement in science has not substantially improved (McConney et al., 2014; Jiang & McComas, 2015). This raises the question of why cooperative inquiry-based science has been ineffective at substantially increasing student outcomes and what is actually happening in the science classroom. A better understanding of what is going on in the cooperative inquiry-based science classroom may enable science educators to capitalise on effective strategies that are working. Similarly, identification of effective strategies that are *not* visible in the cooperative inquiry-based science learning classroom is useful as this may help identify why cooperative inquiry-based science learning has not been as successful as expected.

Elements of cooperative inquiry-based science learning

According to research, for cooperative inquiry-based science learning to be successful, a number of teaching and learning elements need to be present (Lederman et al., 2013; Lin et al., 2015; Minner et al., 2010). For example, teachers need to recognise the fundamental concepts and strategically scaffold students (Gillies & Nichols, 2015; Oliveira 2010) in order to capitalise on teachable moments that arise during instruction (Haug, 2013). Indeed, recent research has focused on the identification of specific types of cooperative group processes and interactions that stimulate successful learning processes (Khosa & Volet, 2014; Salonen, Vauras, & Efklides, 2005; Volet, Summers, & Thurman, 2009). Teachers need to be able to role model cooperative inquiry practices alongside students as more informed investigators (McNeill & Krajcik, 2008). Therefore, they require both the explicit knowledge and skills to actually do cooperative inquiry-based science as well as the pedagogy to successfully implement this approach. At the same time, teachers have their own way of teaching, bringing different interpretations of cooperative inquiry-based science into their classroom teaching. Even within the classroom, the same teacher can and does interact differently with the groups in different circumstances (Lin et al., 2015). Therefore teacher awareness of these types of interactions would benefit cooperative inquiry-based science learning in the classroom.

Similarly, students need explicit knowledge and skills to actually do cooperative inquiry-based science and benefit from explicit instruction in what a cooperative inquiry-based culture involves. Therefore cooperative inquiry-based learning needs to be situated in a cooperative inquiry-based lesson or task (Lederman et al., 2013; McNeill & Krajcik, 2008). At the same time, students need to be explicitly taught what cooperative inquiry-based learning is before they undertake such lessons. This type of specific instruction provides students with necessary skills to effectively support their hypotheses with evidence from their investigations, explain and discuss their explanations, and engage in scientific argument, both linguistically and in written forms (McNeill, Pimentel, & Strauss, 2013). For example, McNeill and Krajcik (2008) found that when teachers explicitly explained scientific explanations, students were able to use this information to construct stronger explanations.

Further to having explicit knowledge and skills of the inquiry process, students require the language of inquiry. Effective participation in cooperative inquiry-based science discourse requires students to have some mastery of the language associated with discussion, argument and debate. Gillies et al. (2014) highlighted the importance of using 'dialogic talk' (p. 127) to promote thinking, problem-solving and reasoning skills in students. Having enriched language skills enables students to manage their assertions and evidence for explanations and/or arguments (McNeill et al., 2013). Importantly, the type and quality of discourse in the classroom shapes students' learning and depth of understanding (Gresalfi, Barnes, & Cross, 2012, p. 253).

Within the language of inquiry learning and central to cooperative inquiry-based science teaching and learning is oral questioning (Oliveira 2010). To enable effective classroom discourse, Gillies et al. (2014) have suggested that teacher (and student) questioning is very important; teacher questioning directly affects classroom discourse (Treagust, 2007). Questioning in science education has a twofold function, one being a communicative function to elicit higher level scientific thinking from students, the other a social function as part of a cooperative, inquiry-based science learning environment. Oliveira (2010) highlights the importance of teacher questioning because it promotes different levels of student thinking, establishes varying degrees of authoritative social relationships with students, encourages students to argue the correctness of their answers, and fosters authentic student inquiries. Teachers (and students), therefore, need to have a clear understanding of the different types of questions available for use in the cooperative inquiry-based classroom context, and the outcome and consequences of their choices and implementation of said questions.

Our interest in this line of research was inspired by the need for a better understanding of group work in an authentic cooperative inquiry-based science setting utilising direct observation of students' interactions with science content, other students, and their teacher (Bennett, Hogarth, Lubben, Campbell, & Robinson, 2010; Summers & Volet, 2010). Although studies have investigated group processes and group interactions that stimulate successful learning processes in the cooperative inquiry-based science setting, the studies have not investigated what is happening in a typical classroom and whether these processes are present in a classroom without direct teacher intervention. The aim of this study therefore is to identify what processes and interactions are occurring in the context of primary cooperative inquiry-based science learning with an experienced teacher.

A framework for studying group interactions

Our analytical framework allows dialogue among group members to be placed along two intersecting continua, interactions among group members and the level of content processing (construction of knowledge). The framework was adapted from previous research to study content processing for examining dialogue in cooperative groups, with an emphasis on regulation (Khosa & Volet, 2014; Summers & Volet, 2010; Volet et al., 2009). In making the adaptations our framework has been modified to remove the emphasis on regulation and to focus on interactions among cooperative group members and the level of content knowledge in the dialogue as students discuss the inquiry task. As shown in Figure 1, the arrow from left to right represents individual to group interactions within the group while the arrow from bottom to top indicates the level of content processing. Specifically, the left side of the arrow represents individual dialogue about the content while group interactions are represented on the right side. Similarly, and from bottom to top, low-level content processing is represented at the bottom of the framework and high-level content processing is represented at the top. Therefore dialogue that represents content processing at the bottom of the framework would be considered at a more basic level while content processing at the top would be seen as higher level content.

As a result of the intersecting continua there are four identified content processing categories. At the top right of the framework is group co-construction of meaning (GCM). High-level content group interactions are situated in this area of the framework. At the top left of the framework is individuals constructing meaning (ICM). This category reflects high-level content dialogue by an individual while below it, individuals clarifying knowledge (ICK), is considered low-level content dialogue by an individual. At the bottom right of the framework is group clarifying and sharing knowledge (GCK). This category represents low-level content group interactions. This conceptual framework and associated coding system forms the analytical framework for the present study.

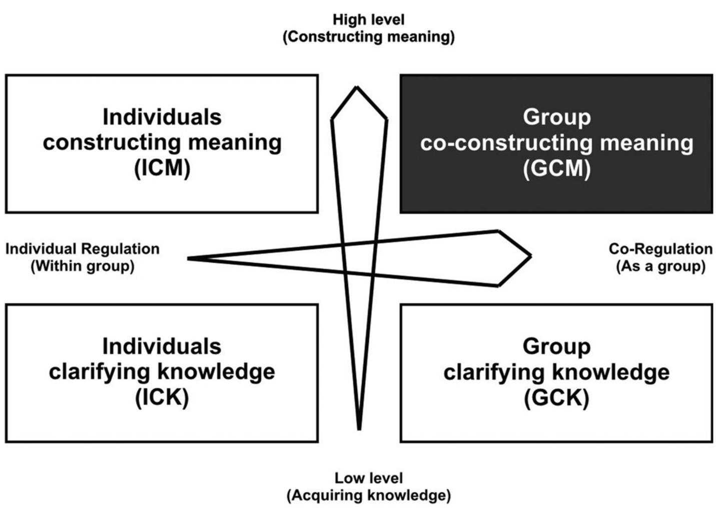

Figure 1. Theoretical Framework for science content processing in a small group setting (adapted from Volet et al. 2009, p. 131)

Purpose

Our purpose in this study is to better understand, through observation and analysis, content-related student interactions in cooperative groups during inquiry-based primary science lessons. It is assumed that when students are engaged in cooperative talk and negotiation of understandings, they may be participating in a process that facilitates deep understanding of scientific concepts. It is unclear, however, whether cooperative talk and negotiation of the science content is happening at a high level in primary cooperative inquiry-based science classes where the teacher has not provided guidance on how to ask questions (Gillies et al., 2014), how to work in groups (Johnson & Johnson, 1994), or assigned group membership for the setting and task. Furthermore, if students are co-constructing meaning in groups (GCM), what context and factors are associated with these high-level group content processing events?

In particular, the study addresses the following research questions:

(1) Does high-level content processing (as measured by GCM) occur in the cooperative inquiry-based classroom setting with 11–13-year-old students?
(2) If high-level content processing occurs, is there a pattern of group or individual student characteristics that may be associated with these interactions?
(3) If high-level content processing occurs, is there a pattern of events (in the inquiry process) that may be associated with or may generate these interactions?

The study

Thirty-one students from two Year 6/7 (Grade 6 and 7) classes in a metropolitan Australian city participated in this study. All student participants, their parents, the principal and the teacher consented to participate in the study. The primary school student population had average socioeconomic status and the school had a typical Western Australian primary school design with all classrooms opening to a covered walkway that directly leads to the outdoor environment. Students frequently use the outdoor setting for learning activities. Science was taught once a week over the 10-week school term. Seven groups of the 11–13-year-old upper primary students were videotaped working in small cooperative groups, both in the classroom and out of doors. The groups ranged in size from 4 to 6 members and, consistent with their normal practice in these classes with this teacher, group membership was based on the students' choices. The groups were not organised with regard to ability or prior knowledge. Three 90-minute science classes were observed with one week between each science class. As detailed below, the first videotaped class was used to acclimate students to the videotaping and data were gathered for the last two sessions. All results and data analysis are based on the last two sessions.

Videotaped data were used during this study for two reasons. First, video data can capture the content of the group activities and the events both visually and with audio. Second, the data can be used for both quantitative and qualitative analysis (Jacobs, Kawanaka, & Stigler, 1999). Furthermore, videotaped data can capture the authentic class setting. In order to ensure the authenticity of data from students' perspectives, video data collection was designed to occur during the normal science class with students videotaping their own group work. To help alleviate the novelty effect of the video camera, students were encouraged to be co-researchers, responsible for the camera and data collection in their group. Each student group was given a video camera to document their interactions in the group. Students were taught how to use the camera as a data collection tool and practiced using the camera the week before video data collection began. Video data for each group were collected during two separate sessions, with each session lasting for approximately 90 minutes.

For the purpose of this research study we characterised cooperative groups as those small enough for everyone to participate and where students are 'expected to carry out their task without direct and immediate supervision of their teacher' (Cohen, 1994, p. 3). For the group work activity in this study, students chose their own groups and were not assigned specific group roles. Students then engaged in a typical science inquiry task that was routinely completed as part of the Year 6 and 7 science curricula.

Task construction

In the task, students investigated and prepared a report that outlined how they would design and construct a theme park ride, 'Ball of Fear' as if they were engineers. Specifically, each group used a 500 mm length of 40 mm polyvinyl chloride pipe and a 25 mm diameter marble to investigate the effect of varying tube angles on the distance a ball would travel and the effect of varying surface types on ball distance travelled. The main learning objective was to identify the factors that would make a theme park ride go as far as possible (Woods-McConney, Wosnitza, & Donetta, 2011). Group members had to plan each investigation, pose research questions and state their predictions. Students discussed the design of their investigation, decided how to gather the data and identified the variables as either independent, dependent or controlled. Students also had to explain how they would conduct a fair test. The groups moved to different areas of the school to discuss the design of their investigation and to try out their ideas with the tube and marble on different surfaces such as grass, concrete and carpet. Group roles were not assigned and students took turns gathering the data, holding the tube and recording the data. Throughout the investigation, the teacher visited student groups and asked questions that could potentially prompt ideas and discussion. Student group members needed to develop conclusions based on the data and relate their findings to what they already knew about kinetic and potential energy.

Coding system

The coding system is based on Volet and colleagues' (Khosa & Volet, 2014; Summers & Volet, 2010; Volet et al., 2009) previous research with university students based on their framework for examining dialogue in cooperative groups, with an emphasis on regulation. Consistent with adaptations in the theoretical framework, in this study the coding system was modified to remove the emphasis on regulation and to focus on interactions among cooperative group members and the level of content knowledge in the dialogue as students discussed the inquiry task. The coding system was also adapted for use in the primary school setting with Year 6 and 7 students. The adaptation of the coding system resulted in a final system with the additional coding category of *content processing events with the teacher present*.

A detailed coding manual was co-developed based on the previously validated coding system (Summers & Volet, 2010; Volet et al., 2009). Operational definitions of each category were included in the manual along with specific instructions for identifying silences and the timing of episodes. In order to adapt the coding for the Year 6 and 7 students, two coders met regularly to interpret the data. Any discrepancies in the coding were decided through discussion, with modifications of the coding system agreed on by the two coders. A new coder interpreted a subset (20%) of the data and was in agreement for 75% of the coding. The coding for the four categories from the framework and *focus on task* will be explained in detail below.

Individuals constructing meaning (ICM)

The high-level content processing events refer to understanding concepts and relationships including how and why something happened. The ICM code was used when an individual student verbalised their high-level thinking. When an individual student drew relations or made comparisons such as 'the ball rolled faster on the concrete than on the grass' and then 'on grass it rolls not as well' the event was coded as an ICM event. Furthermore, statements that reflect a judgement statement, make speculations, infer or link ideas were also coded as ICM events. Therefore when an individual student shared their predictions of the outcome of an investigation, commented on the results of the investigation compared to their predictions, or drew conclusions about the relationships between the variables in the investigation it was considered an ICM event. If an individual gave reasons for why they thought the group should select a certain surface for inclusion in their tests (e.g. *I think we should test on grass next because it is bumpier than concrete and a very different surface*), it was coded as an ICM event. If an individual attempted to explain or apply scientific principles, it was considered an ICM event (e.g. Student 1: *How could we improve it?* Student 1 again*: We could test every 1 cm, but that would take forever*).

Group co-constructing meaning (GCM)

This high-level content processing event also refers to understanding concepts and relationships including how and why something happened. In terms of content processing it is the same as an ICM event. However, for an event to be coded as GCM, multiple group members (two individuals in a group with three students, more than two individuals in a group with four or more students) needed to verbally contribute to the dialogue. Group discussion of scientific principles that apply to their investigation, whether directly content related (e.g. friction, kinetic energy), or related to the scientific investigation (e.g. fair testing), were coded as GCM events. In such discussions group members discussed understanding of these scientific principles as a group taking turns rather than by any single participant. For example, in a group of three students two students discuss their understanding of the results:

C: Okay, so I think this pretty much says that the bigger the angle …
A: … the further it goes …
C: … but obviously like, if the angle is too high …
A: … vertical, yeah, it goes flat.

Individuals clarifying knowledge (ICK)

Low-level refers to content processing that is focused on sharing information (including the reading out/reporting to group of measurements from their tests), clarifying understanding and basic facts, or providing definitions (the what) without evidence of knowledge transformation or integration with an individual's own mental representations. To be coded as an ICK event an individual referred to, read verbatim, or paraphrased from a written source (i.e. the investigation task sheet, class notes etc.). For example, an individual student checking facts in, or paraphrasing details from the investigation task sheet, recalling and conveying face-value information from the brief in-class discussion, or clarifying the meaning of a basic term was considered an ICK event. For example, in a group with three students:

A: It rolls quite well …
C: Yep, pretty good.
A: It rolls quite well on concrete.

Group clarifying knowledge (GCK)

This low-level content processing event also refers to content processing that is focused on sharing information, clarifying understanding and basic facts, or providing definitions (the what) without evidence of knowledge transformation or integration with one's own mental representations. To be coded as GCK the majority of group members (two in a group of three students, more than two in a group of four students) needed to make verbal contributions that involved checking facts in, or paraphrasing details from the investigation task sheet, recalling and conveying face-value information from the brief in-class discussion, or clarifying the meaning of a basic term (e.g. *What does hypothesis mean? It means your prediction*).

Collecting the raw information from which knowledge was constructed, such as the sharing of measurements of distance, angle, time the ball rolled for (for example) is part of what was coded as GCK. Furthermore, episodes that involved discussion between group members about how they should be handling measurement equipment to get an accurate result was considered a GCK event if it involved science knowledge:

C: So I put it on the ground?
A: Sure, just roll it.
A: So it roughly went for about 3 seconds.
C: Yeah, we'll time it this time.
C: 1 … 2 … 3 … 4 … 5

Focus on task

Within the scope of primary school science cooperative inquiry-based science activities, *focus on task* involved dialogue related to aspects of the activity that were not related to the science content. These events included discussions such as deciding which of the two science inquiry variations the group would select, what format they are meant to use to write up the investigation, choosing which teacher predetermined aim to focus on, listing materials (without discussion of *why* they think they should write a certain thing), conversation related to the operation of the camera (e.g. *it's recording and I'm not joking*), and discussion of which surfaces or angles the group would include in their investigation (without discussion of *why* they were selecting them). For example:

D: I think we should just try …
J: Yeah, let's try it on the oval now.
T: Try it on the Oval?

Results

Coding for the seven student groups resulted in a total of 1199 events. As might be expected, many of the 1199 events were coded as non-content processing related events such as *focus on task* (416 total events, 34.7% of total events). In terms of individual and group member content processing, 234 events were coded as individual content processing (ICM and ICK) and 198 events were coded as group content processing (GCM and GCK). Therefore, group content processing comprises 16.5% of *all* events while individual content processing within the group encompass 19.5% of *all* events. Looking at all group content processing events, only 42 out of 198 revealed high-level content interactions, which comprise 21.2% of group content processing and 3.5% of all activities (about 19 minutes in total combining all group times). These results indicate that high-level group interactions did occur during the science inquiry activities, but at a minimal level for these 11–13-year-old students.

At the group level the data reflect a more differentiated picture. As shown in Table 1, the seven groups differ in the frequency (n), ratio (per cent of individual group activities compared to overall activities) and duration (both in terms of overall time spent and the time per event) of the group high-level content-related interactions. Looking at the first row of the table, three groups had very low frequency and duration of interactions (A1, A2 and A3), three groups had quite similar but modest levels of the frequency and durations of interactions (B1, B2 and B3), and one group (C) was distinctive in terms of the frequency and duration of the high-level content-related group interactions. As seen in the second row of the table, the range of incidences of content processing ranged from 95 incidences for group B1 and only 32 events for group A2. Despite this very large span in the frequencies the proportion of content processing for all groups is

Table 1. Content processing

	C1 (6)	B1 (1)	B2 (2)	B3 (4)	A1 (7)	A2 (5)	A3 (8)
% of *high-level group co-construction* of meaning of all activities (GCM)	6.51 (n = 11)	3.63 (n = 9)	9.18 (n = 9)	4.90 (n = 7)	1.53 (n = 3)	1.71 (n = 2)	0.44 (n = 1)
% of *content processing* of all activities (ICM, GCM, ICK, GCK)	47.93 (n = 81)	38.30 (n = 95)	38.78 (n = 38)	28.67 (n = 41)	32.14 (n = 63)	27.35 (n = 32)	35.96 (n = 82)
% of *high-level content processing – constructing meaning* of all activities (ICM, GCM)	19.53 (n = 33)	16.13 (n = 40)	18.37 (n = 18)	12.59 (n = 18)	7.65 (n = 15)	9.4 (n = 11)	7.01 (n = 16)
Overall time spent on GCM (seconds)	467	190	166	205	57	52	8
Average GCM time spent/incident (seconds)	42	21	18	29	14	26	8

much more comparable. In all groups about a third of all group activities were categorised as content processing (with the exception of C1 47.9%).

Focusing on high-level content processing (Row 3), the differences between the groups become more obvious. The proportion of all activities categorised as high-level content processing ranges between 19.53% and 7.01% with a median of 12.59%. Group C1 showed the highest and Group A3 the lowest content processing/activity ratio of all groups. Central to this study is whether primary school students involved in cooperative inquiry-based science activities are able to construct meaning at a high level (GCM). The data show that all groups have incidences of GCM. However, there is a considerable range of incidences with $n = 1–11$ and a median of 7 GCM events. Group C1 ($n = 11$) showed the highest number of GCM events, students in Group B2 exhibited the highest proportion of GCM of all group activities (9.18%) and Group A3, with only one incident also had the lowest GCM event overall ratio (0.44%). The groups also differed regarding the time they spent on GCM. Students in Group C1 spent the most of time (467 seconds) engaged in a GCM event and Group A3 the least amount of time (8 seconds) engaged in GCM events. With an average of 42 seconds, students in Group C1 also had the longest average GCM time per incident and students in Group A3 the shortest average GCM time (8 seconds) spent in GCM interactions.

GCM happens differently in different groups

As might be expected, an overview analysis showed that students in the different groups interacted differently, with no consistent pattern. In order to clarify how students interacted with one another during a GCM event, three vignettes are provided. The two extreme groups with the lowest (Group A3) and highest (Group C1) content processing/activity ratio events are provided, along with the group that had the highest proportion of GCM compared with all group activities (Group B2).

Group A3

Group A3 consists of five students. In this vignette they are filling out their exercise sheet and discussing plans about what they are going to do. This GCM event is at the beginning of the two days of student data collection. Students are discussing the surface they will choose and how they will proceed. All five students are completing the sheet and one student is looking on but not speaking. The GCM event occurs for 8 seconds and there are some pauses as the students speak:

S1: I reckon it will go the furthest …
S2: on concrete …
S3: That's because it isn't bumpy.
S4: So … (writing on the sheet)
S5: I reckon it would.
S6: Not speaking but writing on her sheet.

Group C1

Group C1 also consists of five students but this vignette is after their last data collection activity. The students have moved to an inside area to complete a group sheet. They discussed the results as they walked to the inside area. The vignette starts as they are settling down to a sitting position with one student writing on the sheet:

S1:	Ok, so uhm. By far, it looks like bitumen was the best,
S2:	at seventeen eight one centimeters!
S3:	It rolled well.
S4:	yeah because. ok, well … .Carpet was pretty good because like
S1:	It was smooth
S4:	It hasn't got any lumps
S1:	It's got a bit of friction in it
S4:	Yeah that's why it didn't go as far because it like it's got friction. Uhm … The concrete …
S5:	Bitumen was first, concrete …
S3:	No let's do it uhm first second, third, all up.
S1:	Writing
S3 and S2 almost at the same time:	Bitumen …
S5:	Bitumen was first,
S4:	It didn't … wait, because it didn't like.
S5:	then carpet …
S4:	Why is bitumen first is all I'm saying.
S5:	The marble went further …
S3:	*Writing on the sheet*. I'll work it out
S5:	… that's why it's first!
S2:	Averaged
S4:	Cause its gotta go like … .sometimes didn't it go like sometimes bumps it can keep it rolling. Instead of … instead of if there's no bumps it stops … bit if it gets bumps it keeps going, ya know?
S1:	yeah it goes … and makes a motion with his hands.
S5	is shaking his head and then contributes to the conversation later, after the end of this vignette.
S4:	Uhm, the reason concrete was … concrete was pretty good, but it
S2:	Wasn't the best
S4:	Yeah, grass was … grass was okay but it didn't get any
S1:	It went better than what we'd thought …

Group B2

This group consists of four students with one student refusing to participate. The three active group members talk at the same time and finish one another's sentences. This vignette is during data collection and the students started talking about the results after they rolled the marble down the tube:

S1:	Wait, that was a bit of a *(minor expletive)* one
Concurrently:	S2: Yeah, cause it went in there … S3: It went

S1:	Well, it went in the crack. It rolls … Well we get …
S2:	You get … It rolls …
S1:	It rolls good on … . It rolls better … .
S1 & S2 together:	on concrete than grass.
S3:	Or … .
S1:	So we'll do our experiment on grass … I mean concrete. Laughter
S2:	… concrete
S1:	We'll try different surfaces.
S3:	Maybe we could like …
S2:	It could be like …
S1:	And time … and measure the distance
S2:	We could see how the …
S3:	… try sand and grass, concrete.
S1:	We'll try all the surfaces that we can find.
S2:	Let's just do that.

Is there a pattern with the events that occur before the GCM event?

To better understand the nature of GCM and whether there is a pattern of events that may have triggered or generated GCM events, we analysed the data for any patterns of events among the groups. Each GCM event was analysed to identify what happened immediately before it occurred. Of the 11 total coded categories that could potentially trigger a GCM event, only five categories were observed before the GCM event. These five categories included ICM with a frequency of nine times before the GCM event, ICK with four times before the GCM event, GCK with five times before the GCM event, *focus on task* with 23 times before the GCM event, and *socialising* once before the GCM event. Interestingly, three of these five categories were content processing events (ICM, ICK and GCK). The most frequent trigger event was focus on task, which is not surprising given the prevalence of focus on task events (416 events, 34.7%) throughout all group activities. Although there was no pattern of generate type events, the most interesting result from this analysis is the lack of teacher interactions to generate GCM events.

If the teacher is not triggering a GCM event, what is the teacher doing?

Although the teacher was not prompting the GCM events he was interacting with students in the groups. Three types of interactions were identified with the 32 teacher-group interactions:

- The teacher provided instructions that were closed and directive,
- provided open questions and guidance or
- requested a summary of the students' group work.

Closed and directive instructions

While groups were completing the inquiry activity in separate areas, the teacher entered one area and observed a group of students before asking questions:

Teacher: Ok, so if you don't measure the angle because you haven't got a protractor here, what would you measure instead?
S1: Centimeters
Teacher: Ok, the centimeter height. So what you have to do, is you guys need to do this experiment … You guys need to do your test. But what you guys need to do first is you need to do is to discuss, you need to discuss exactly how you guys are going to do it. So don't worry about writing at the moment … . You've talked about those things … discuss as a group, how you're going to do your test, how its going to be a fair test. What are you going to be controlling, what are you going to be changing. So that you can actually achieve this. You guys need to do the test … pause …

Students are writing:

Teacher: How are you going to report your results. What units are you going to use to record your results. Once you've determined that, exactly how you're going to do it, I want you to try it. Go for it, you've got a task.

Open questions and guidance

Again, while groups were completing the inquiry activity in separate areas, the teacher entered one area and observed a group of students before interacting with them:

Teacher: I've got a conflicting thing in my head. I'm really concerned about something. Thinking about the school here. We've got bitumen and we've got concrete, so like the concrete path, guys. I've got a prediction in my head that I think that the marble would roll further on the concrete.
Students: Yeah, yeah
Teacher: What do you reckon?
Students: What is bitumen?
Teacher: This is bitumen, the black is bitumen and the pathways are uh, concrete.
S1: What about the assembly hall?
Teacher: Ahhh. The assembly hall is bitumen as well. So which one do you reckon?
S2: I think it's the smooth one.
Teacher: You're saying the smooth one. You're saying the bitumen. Would you consider adding that as another surface in your, in your uhm experiment?
Students: Yeah
Teacher: But the grass is a different surface isn't it? So you've got data for grass. How about you give that a go guys. And, at the end I want you guys to actually come up … or when you've finished could you let me know. I reckon, I think it's the concrete. I'm going to ask other groups as well. All right? Thanks guys.

Summary of group's progress

Students are completing their sheet, asking each other questions. Three of the four students are engaged in the discussion, one student is completing his sheet slowly and seems on task but is not participating in the conversation:

Teacher:	Hey guys how'd you go with your test
S1, S2 & S3:	Good.
S2:	We uhm we did three uhm three different uhm sizes. We did … one that was low to the ground, one that was … middle and one that was higher and … (as she is speaking she tilts the pipe showing the different angles)
Teacher:	Did you actually take measurements?
S2:	Yeah
S1 & S3:	Yeah
S2:	Yeah we measured how far …
Teacher:	So how high was the lowest one?
S3:	uhm, 5 centimeters
S2:	no they're inches
S3:	No they're not inches,
S1:	57 … it went 57 centimeters.

In summary, different patterns of useful (cooperative and inquiry learning) behaviours seemed to be associated with the frequency and duration of high-level content-related group interactions while no specific pattern of preceding events was identified across all groups. Additionally, teacher's interactions with the groups did not immediately trigger episodes of high-level content-related group interactions.

Discussion

The results indicate that the answer to the first research question, *Does high-level content processing (as measured by group co-construction of meaning) occur in the cooperative inquiry-based science classroom setting*, is affirmative. High-level content processing did occur in the cooperative inquiry-based science classroom context, although not for an extensive amount of time. The maximum amount of time spent engaged in GCM was 7.8 minutes out of a total of 180 minutes (two 90 minute lessons), which equates to approximately 4.3% of the lesson time. These results differed from a similar study by Summers and Volet (2010) who reported groups spent, on average, 11.0% of their time engaged in GCM. This differentiation may be explained by the age and experience of the students in the two studies, as Summers and Volet (2010) worked with university students who are likely to be more knowledgeable and experienced with cooperative and inquiry-based learning.

The students in this study did not engage in behaviours that would provide the most learning benefits in the cooperative inquiry-based science learning situation which may have contributed to the brief amount of time spent in GCM. Prior to this study the students had not experienced explicit teaching in cooperative inquiry-based strategies and the associated language of inquiry, a strategy known to improve student engagement in cooperative inquiry-based science learning (Bennett et al., 2010; Gillies et al., 2014; Gresalfi et al., 2012; Kershner, Warwick, Mercer, & Kleine Staarman, 2012; Lederman et al., 2013). This is not uncommon in the primary school setting. Simply putting students in groups does not provide the necessary knowledge and skills for them to effectively engage in the cooperative inquiry-based science setting. It cannot be assumed students will spend a significant amount of time in high-level content-related discussion simply because the students are in groups (Belland, Kim, & Hannafin, 2013; Khosa & Volet, 2014; Summers & Volet, 2010). Without being explicitly instructed in cooperative and inquiry learning, students may not be *aware* of the opportunities available to help them engage with the lesson (Gresalfi et al., 2012; McNeill & Krajcik, 2008) or may not have the necessary skills (Bennett et al., 2010) to enable their success with cooperative inquiry-based learning.

In relation to the second research question, *Is there a pattern of group or individual student characteristics that may be associated with high-level content processing interactions*, no specific pattern of group or individual student characteristics was present. The amount of time spent on GCM varied considerably between groups and there appears to be no single or group of conditions that precipitates GCM. Of the four groups who spent the most overall time on GCM, two had emergent leaders. Group C1 had a functional emergent leader who continually asked *What do you reckon?* thus providing scaffolding for, and engaging the other members of the group in effective cooperative inquiry learning questioning. Emergent leaders were also evident in a similar study (Summers & Volet, 2010), where one student engaged in persistent content-related questioning. In addition to having the highest percentage of GCM, students in Group C1 also spent the most time (7.8 minutes) engaged in GCM and the most time spent in GCM per event (42 seconds/event). Group B2 also had a (non-functional) emergent leader, however this student did not do any work or write up the activity, he simply worked out the answers and was then engaged in off-task behaviour. Interestingly this group had the highest GCM percentage of all activities.

The emergent leader in Group C1 acted to co-regulate the behaviour of the other members of the group. For co-regulation to occur it requires a student and a significant, more capable other who asks questions to prompt or cue (scaffold) the learner (Dinsmore, Alexander, & Loughlin, 2008; Hadwin & Oshige, 2011); in this study the emergent leader acted as the significant other, rather than the teacher. It is interesting to note that group B3 had a slightly higher percentage of time spent on GCM than group B2 (4.1% and 3.1%) and did not have an emergent leader, suggesting high-level content processing may not be dependent on a leader emerging in a cooperative group.

In answer to the third research question, *Is there a pattern of events that may be associated with or may generate the high-level content processing interactions*, no specific pattern of events was associated with or generated high-level content processing. The behaviour that occurred prior to a GCM event was most commonly *focus on task*. Similarly, statements or questions were observed to most commonly precede GCM events for tertiary students (Volet et al., 2009).

Interestingly, teacher interactions was not an event that generated GCM, which reflects the results of Gresalfi et al. (2012), who found that teacher prompts tended to result in alternative forms of engagement, rather than the intended critical or high-level engagement. However, teachers were found to influence peer collaboration in another study (Lin et al., 2015) that investigated relational thinking, a high-level content interaction that involves the members of the group. The study by Lin et al. (2015) showed that the level of teacher questioning tends to elicit the same level of student response, so a high-level prompt would result in a high-level response by student(s). Similar to the results by Lin and colleagues, teachers often think they need to facilitate student learning by prompting high-level interactions.

Our results, however, do not support this commonly held perception. In our study the teacher was not needed to facilitate high-level content group interaction for the upper primary school students. If however, *focus on task* is the behaviour that most often precedes a GCM event, then teacher questioning that does not directly generate higher level thinking may serve a focussing function on what is important to complete the activity (Campbell & Erdogan, 2008). This focussing could indirectly promote GCM through initiating a *focus on task* event. At the same time, it would serve teachers to be mindful of their management of the student groups because as Lin et al. (2015) found, cognitive management in the form of 'redirecting off-task ideas, summarising student opinions' may impede students' higher level thinking (Lin et al., 2015). Clearly, further research is needed.

What should teachers do when they interact with cooperative inquiry-based science groups? The research is not clear. However, what is clear is that there can be difficulties in teaching cooperative inquiry-based science skills to students. There are not enough examples in the literature of its successful implementation (Asay & Orgill, 2009) and there are too few examples of what inquiry teaching looks like in the classroom. This further compounds the difficulties for both pre-service and in-service teachers looking for evidence to support their practice.

Given the difficulty of implementing inquiry learning, the minimal amount of GCM experienced by the groups in this study is not surprising. The difficulties of inquiry learning may contribute to the suggestions that inquiry learning does not necessarily result in higher student achievement (McNeill et al., 2013). Furthermore, increasing the amount of time engaged in overall inquiry learning does not automatically correlate with an increase in student achievement, as observed by Minner et al. (2010). So where does this leave the classroom teacher who is trying to use cooperative inquiry-based science teaching and learning activities to enhance student science learning? The success of cooperative inquiry-based science learning is dependent on teachers' ability to positively implement inquiry pedagogy and learning activities in the science classroom. For successful cooperative inquiry learning teachers need to have a clear understanding of what cooperative inquiry science instruction looks like in the classroom and have the essential skills required to *explicitly teach* students what cooperative inquiry science is and how they can participate in such activities. This may include, but is not limited to, teaching the language of discussion and argument, participating in group interactions including questioning, discussing, debating and voicing, and students using evidence to support their opinions. Teachers need to develop an ongoing review of their cooperative and inquiry-based pedagogy, to ensure their practices and understandings are aligned with inquiry teaching and learning principles.

Although numerous studies have investigated the conditions, skills, knowledge and pedagogy associated with cooperative inquiry-based teaching and learning, there are few in situ studies (Bennett et al., 2010) and even less consistent evidence of specific conditions that may improve student engagement and outcomes. This in situ study therefore demonstrated that even without any kind of scaffolding, specific skills in knowing how to implement cooperative inquiry-based science, GCM occurred. It did not last long, but it was there. Imagine the potential if teachers are supported in developing their skills to facilitate cooperative inquiry-based science learning.

Disclosure statement

No potential conflict of interest was reported by the authors.

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