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Individual to collaborative: guided group work and the role of teachers in junior secondary science classrooms

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ABSTRACT

This paper, through discussion of a teaching intervention at two secondary schools in Hong Kong, demonstrates the learning advancement brought about by group work and dissects the facilitating role of teachers in collaborative discussions. One-hundred and fifty-two Secondary Two (Grade 8) students were divided into three pedagogical groups, namely 'whole-class teaching', 'self-directed group work' and 'teacher-supported group work' groups, and engaged in peer-review, team debate, group presentation and reflection tasks related to a junior secondary science topic (i.e. current electricity). Pre- and post-tests were performed to evaluate students' scientific conceptions, alongside collected written responses and audio-recorded discussions. The results indicate that students achieved greater cognitive growth when they engaged in cooperative learning activities, the interactive and multi-sided argumentative nature of which is considered to apply particularly well to science education and Vygotsky's zone of proximal development framework. Group work learning is also found to be most effective when teachers play a role in navigating students during the joint construction of conceptual knowledge.

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Collaborative discussions; conceptual knowledge; current electricity; group work; physics education

Background

In recent decades, Hong Kong has occupied an enviable position in many educational league tables (Carless & Lam, 2014; Organization for Economic Cooperation and Development, 2010), such as the Trends in International Mathematics and Science Study (TIMSS), Programme for International Student Assessment and Progress in International Reading Literacy Study. From 1995 to 2011, Hong Kong students achieved consistently high scores in both science and mathematics in TIMSS, which is conducted in four-year cycles (Martin, Mullis, Foy, & Stanco, 2012). However, although Grade 4 (Primary 4) students in Hong Kong perform well in elementary science (i.e. ranked 10th in 1995, 4th in 2003 and 3rd in 2007), that momentum is generally not sustained once they are promoted to Grade 8 (Secondary 2) (i.e. ranked 15th in 1999, 9th in 2007 and 8th in 2011), whereas their Western counterparts achieve relatively consistent results over time (Mullis, Martin, & Jones, 2014). For example, Grade 4 students in England ranked

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fifth and seventh in 2003 and 2007, and Grade 8 students fifth and ninth in 2007 and 2011, respectively.

Pedagogically speaking, this issue is considered relevant to the educational reform outlined in the blueprint 'Learning to learn – the way forward in curriculum' (Curriculum Development Council [CDC], 2001), which encourages Hong Kong teachers to adopt diversified teaching strategies to promote more active student participation (Tsai, 2003). Indeed, since the reform's launch, the use of group work in primary classrooms has increased (Galton & Pell, 2010; Keppell & Carless, 2006), and positive academic and attitudinal changes have been observed amongst students (Fung, 2014; Kutnick & Blatchford, 2014). However, although group work is recognised as a compelling way of advancing primary education in Hong Kong, this instructional approach is still relatively underplayed in secondary schools and perhaps under-valued in science teaching (Fung & Yip, 2006; Education Bureau, 2008; Fung & Howe, 2014; Tao, 2003). Two questions of interest are thus (1) whether the failure to exploit the potential of group work in secondary schools is responsible for the aforementioned discontinuity of progress in science and (2) whether Hong Kong students perform better in a collaborative rather than independent science lesson environment.

To address these issues, the study reported herein built upon earlier research on the benefits of group work and extended it to the context of science education in Hong Kong. By analysing the pre- and post-test results of different pedagogical groups in a teaching intervention, the study contributes valuable data illustrating the relevance of group work to the fostering of science learning, examining in particular the teacher's role in collaborative tasks. These data will afford a better scholarly understanding of how collaborative strategies can help teachers to design contexts that minimise rote learning and maximise learning motivation in the science classroom.

Teaching science through a constructivist approach

Collaborative group work has become an increasingly popular classroom strategy in the West since its introduction in the 1960s, particularly in early childhood and primary education (Lyle, 1996; Rohrbeck, Ginsburg-Block, Fantuzzo, & Miller, 2003). A recent review of research in this area (particularly in the form of year-long interventions) reveals that group work facilitates students' acquisition of theoretical understanding and reasoning ability (Gillies & Haynes, 2010). With its emphasis on 'peers working together to solve problems [that] they may not be able to solve alone' (Lumpe & Staver, 1995, p. 73), group work seems a promising pedagogical strategy for tackling science concepts at a high cognitive level (Springer, Stanne, & Donovan, 1999). Although it is arguable whether all group-generated views are internalised by group members when assessed individually (Howe, Tolmie, Greer, & Mackenzie, 1995), positive results in terms of students' conceptual changes have been obtained across a wide age range and broad selection of science topics (Bowen, 2000; Day & Bryce, 2013; Simsek, 2012).

Over the past few decades, despite the peer-learning approach gaining in popularity and acceptance amongst classroom researchers, a degree of uncertainty persists about the role of the teacher in small-group interactions. In fact, as groups are collections of individuals, conflicts are inevitable during group discussions (Cohen, Lotan, Scarloss, Schultz, & Abram, 2002), raising the question of how students can improve their own understanding of the subject and how they perceive their opponent's rationale when their scientific concepts are challenged (Chin & Osborne, 2010; Dreyfus, Jungwirth, & Eliovitch, 1990; Fordham, 1980; Tsai, 2003). In response, some science educators (e.g. McNeill & Pimentel, 2010) emphasise the crucial role of the teacher in group discussions, noting that his or her use of prompts or open questions can encourage students to apply their science knowledge to make informed decisions. Other small-group theorists (i.e. MacKenzie, 2001; Martin & Hand, 2009) have made a similar argument, positing that teacher questioning can trigger divergent modes of thinking in students and promote an upward shift from factual recall to higher order skills in the primary science classroom.

Looking through a more philosophical lens, there is strong consensus that the power of group work lies in its synergy of theory and practice (Slavin, 1995). In other words, without an appropriate theory, practice becomes static and stagnant. Although some of the greatest educational theorists of the twentieth century focused on cooperation, the use of group work in the classroom has its roots in cognitive-development theories (Johnson, Johnson, & Smith, 1998). One of the most fundamental of these theories was proposed by Piaget (1928), who highlighted the importance of the interaction of social, affective and cognitive states in development and learning, providing a theoretical rationale for the use of group work in classroom practice. Another theory that envisages an intimate relationship between group work and cognitive-development stems from the work of Vygotsky (1978). The Vygotskyan view, which encourages weaker students to learn from high achievers, favours the use of grouping in instructional settings. In an epistemological sense, Vygotsky believed that knowledge is socially legitimated and that children require induction into it. A discrepancy between solitariness and social problem-solving may exist within what Vygotsky (1978, p. 86) defined as the 'zone of proximal development' (ZPD). More recently, the social constructivism derived from the Vygotskyan model, which focuses on expert guidance as support for procedural mastery, has gained support in the science arena (e.g. Leach & Scott, 2003; Mercer, 2015; Soong & Mercer, 2011), with researchers showing that such guidance can in principle be provided by relatively skilled partners in the group setting.

Building upon these theories of constructivism with regard to children's cognitive development, the study reported in this paper developed a teaching intervention in the context of the Hong Kong secondary science curriculum to investigate students' joint construction of conceptual knowledge through a combination of group work strategies. Informed by an adapted conceptual framework underpinned by the work of Vygotsky (1978) with three independent domains – 'whole-class teaching', 'self-directed student group work' (SDGW) and 'teacher-supported group work' (TSGW) (Figure 1) [this figure was also presented in Fung, To and Leung (in press)] – the study examined the relationship between different types of pedagogy and students' science learning. It was guided by two research questions:

1. How does group work affect student learning in junior secondary science classrooms in Hong Kong?
2. Does TSGW better facilitate students' science learning than self-directed group work?

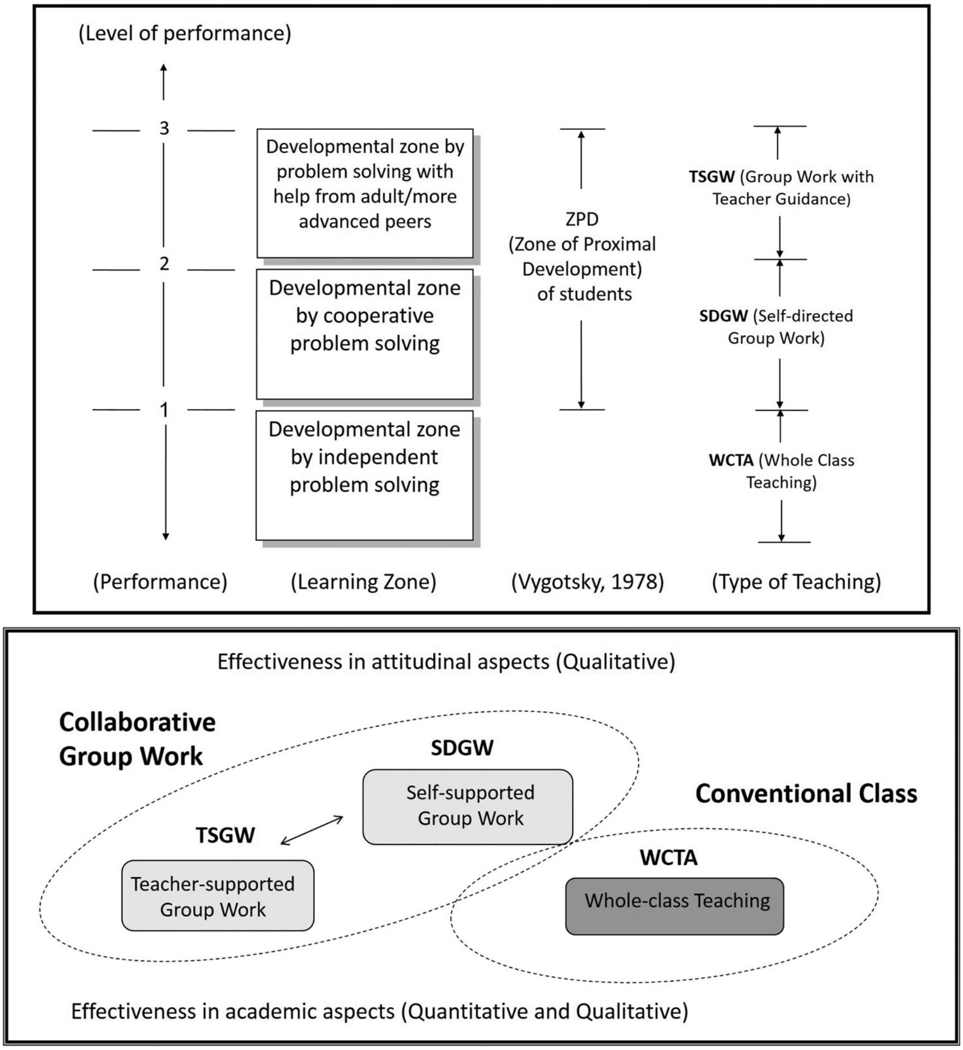

Figure 1. Adapted conceptual framework and anticipated development of students in the study.

The present study

Participants and research design

The study was supported by a competitive government funding scheme offered by the Hong Kong Research Grants Council and carried out in two secondary schools in Hong Kong. The schools were randomly recruited from a list of 40 partnership schools with strong collaborative ties to the research team's host institution, and admit mostly Band 2 students (the medium band in the three-tier system classifying secondary school students in Hong Kong). The participants in each school were two whole classes of Secondary 2 (or Grade 8) students between the ages of 12 and 14, and thus four classes with a total of 152 students participated in the study. Boys ($N = 86$) constituted a small majority (approximately 57%) of the total sample.

Table 1. Quasi-experimental setting of present study.

Each school	Quasi-experimental design Class A	Class B	
Setting	Control group	Experimental group	
Classification	WCTA	SDGW	TSGW
Pedagogy	Conventional class ($N = 38$)	Self-directed group work ($N = 22$)	Teacher-supported group work ($N = 16$)
Group size	N/A	Around 7–8 students	
Number of groups	N/A	3	2

To explore the impacts of different pedagogical practices on students' learning of science, the research was designed as a quasi-experiment (Table 1). Each participating school was asked to randomly select two classes (each with approximately 38 students) of the same academic level. A whole-class teaching approach (WCTA) was applied in Class A, which acted as the control group. In the experimental group (Class B), in contrast, teaching was carried out via group work. The experimental group was divided into five sub-groups, two of which were TSGW groups and three of which were SDGW groups. In the two TSGW groups, discussions and interactions were facilitated by teachers, and guidance was provided, whereas students in the three SDGW groups engaged in self-directed group learning without any help from teachers. All of the students in Class B were randomly assigned to these sub-groups and collaborated on the tasks assigned in the teaching intervention, whereas their Class A counterparts subjected to WCTA were instructed to perform the tasks independently rather than collaboratively.

Teaching intervention

The teaching intervention was carried out in 16 successive lessons in which one of the Hong Kong junior secondary science curriculum units, 'Making Use of Electricity' (CDC, 1998), was taught. The 16 lessons, each lasting one and a half hours, took place in the first month of the four-month-long unit. A set of adapted TIMSS questions was employed in the intervention and students were asked to participate in group tasks such as peer-reviews, argumentative discussions and self-evaluation. Pre- and post-tests were administered at the beginning and end of the teaching intervention for diagnostic purposes. The pedagogical procedures in four separate lesson phases are summarised below.

Phase I – peer-review task

Students were asked to work in pairs on a given adapted TIMSS question related to scientific inquiry, an example being the working principles of a lightning rod. The two partners first formulated their thoughts on paper and drew their own hypotheses and deductions to predict experimental results, and then exchanged ideas. Afterwards, they proposed arguments against each other's ideas in written form. The aim of this task was to encourage students to support their reasoning with evidence and to engage in peer-review through critiques.

Phase II – group debates

Each SDGW and TSGW sub-group in the experimental class engaged in a 15-minute debate on a particular topic (e.g. how lightning rods channel an electric charge to the ground), with its members split into 'for' and 'against' teams. In the TSGW groups, teachers took part in the debates by facilitating students' interactions, encouraging them to speak up and share ideas, and suggesting directions when discussions reached a dead end or deadlock, but did not intervene to the extent of preventing students from generating their own arguments. In response to challenges raised by the opposing side, students put forward reasons for their positions, and finished the debate by commenting on fellow group members' performance.

A new round of debate then followed, with teams switching sides. By asking students to formulate both for and against arguments, this activity urged them to rethink and question their beliefs about and knowledge of a science proposition through joint efforts and communication.

Phase III – group presentations

Each sub-group reported on the consensus reached by its members once the debates were finished, bringing closure to the discussion topic. In the process of articulating what they had learnt and understanding other groups' points of view, the students were guided towards exploring the scientific concept deeply and critically, reminded to always keep their minds open and, most importantly, informed of how to build knowledge through collaboration. Task sheets were handed out to help students to improve through self-reflection.

Phase IV – reflection, feedback and student assignments

Students were encouraged to reconsider their initial arguments after listening to different opinions and receiving feedback on their classmates' oral and written presentations. Finally, they were instructed to answer the question from Phase I with reference to the consensus view reached after the group debates.

The same TIMSS question was assigned to the WCTA control group, albeit in a very different manner. Unlike the SDGW and TSGW students who worked in groups, the WCTA students were asked to finish the tasks individually in their own seats in a traditional classroom setting with whole-class teaching. The control group students gave individual presentations and engaged in question-and-answer sessions, class debates and reflection individually, with the teachers playing only a monitoring role, ensuring that students were given enough time to complete their work and that the scientific topics selected were thoroughly discussed in class. At the end of each lesson, those who had performed well in answering the adapted TIMSS question were asked to share their ideas with the rest of the class.

Instruments, data collection and analysis

Three main sources of quantitative and qualitative data were collected in the study. The procedures for the collection and corresponding analysis of each data source are described below.

Diagnostic questions

All participating students were administered an identical set of diagnostic questions as a pre- and post-test of the intervention. The questions were extracted from an Evidence-based Practice in Science Education (EPSE) Research Network[1] (Millar & Hames, 2006) project comprising 20 items associated with current electricity (sample questions are shown in Appendix 1). The items probe students' ability to identify correct scientific concepts and common-sense alternatives (Whitehouse, 2012), and have been employed in numerous projects (e.g. Ratcliffe, Osborne, Collins, Millar, & Duschl, 2001) investigating students' development of conceptual knowledge in independent and collaborative learning environments. Mixed-design analysis of variance (ANOVA) was performed to determine whether the students in the experimental group improved significantly in the post-test relative to the pre-test compared with those in the control group.

Written responses to adapted TIMSS questions

As previously noted, a set of TIMSS questions ($N = 16$) matching the Hong Kong junior secondary science curriculum was adapted for use in the group activities during the teaching intervention. This set of structural science questions[2] was piloted in 24 secondary schools in Hong Kong prior to the present study, with the results showing a satisfactory internal consistency level ($\alpha = .81$) and discrimination index (14 of the 16 questions reached $d' = .62$). The questions cover several sub-topics on current electricity (e.g. 'simple electric circuits' and 'resistance, voltage and current') in the local science curriculum, and serve as a means of probing students' scientific reasoning and preconceptions. Students' written responses to the adapted TIMSS questions were collected throughout the teaching intervention, thereby providing evidence of the impact of group work interactions on their development of scientific thinking. More than 400 pieces of written work were collected, subjected to content analysis and subsequently compared across the control and experimental groups.

Audio-recordings of group discussions and individual presentations

To compile evidence of students' construction of conceptual knowledge, student dialogues in both participating schools were audio-recorded throughout the intervention to permit scrutiny of their speech (science discourse) in group discussions (i.e. SDGW and TSGW) and individual presentations (i.e. WCTA). The SDGW and TSGW groups were all audio-recorded twice, and the amount of talk per student group was 25–30 minutes per lesson. For the WCTA class, around 25 minutes' worth of individual student presentations was recorded in each intervention session. More than 40 discussion sessions and presentations were audio-recorded in total. For data analysis, the audio-recordings were transcribed and coded by the principal investigator and a research assistant, and the five-level analytical framework developed by Osborne, Erduran, and Simon (2004) was adopted to assess the quality of students' argumentation in the transcripts (Table 2).

Results

Pre- and post-diagnostic tests

ANOVA was performed to make comparisons across the three pedagogical groups. To investigate the effects of the two independent variables, that is, (a) *teaching pedagogy* (WCTA, SDGW and TSGW, between-participants factor) and (b) *test* (pre- and post-test, within-participants factor), on the diagnostic test scores, a 3 (WCTA, SDGW and TSGW) x 2 (pre- and post-test) mixed-model ANOVA design was adopted.

ANOVA revealed *test* to have significant main effects: $F(1,298) = 4.29$, $p < .05$, partial eta squared (η^2) = 0.23;[3] that is, the diagnostic test scores for all of the pedagogical groups were higher at the post-test than at the pre-test, and the difference amongst them was significant (Figure 2). *Teaching pedagogy*, in contrast, had an insignificant main effect ($F(2,298) = 0.54$, ns), although there was a significant interaction effect between *test* and *teaching pedagogy*: $F(2,298) = 4.63$, $p < .05$, $\eta^2 = 0.19$. To explore the nature of these interactions, post-hoc tests

Table 2. Framework used to assess argumentation quality (Erduran et al., 2004).

Level 1	Level 1 argumentation consists of arguments that are a simple claim versus a counter-claim or a claim versus a claim
Level 2	Level 2 argumentation has arguments consisting of a claim versus a claim with either data, warrants or backings, but does not contain any rebuttals
Level 3	Level 3 argumentation has arguments with a series of claims or counter-claims with either data, warrants or backings and the occasional weak rebuttal
Level 4	Level 4 argumentation shows arguments with a claim with a clearly identifiable rebuttal. Such arguments may have several claims and counter-claims
Level 5	Level 5 argumentation displays an extended argument with more than one rebuttal

were conducted to evaluate the pair-wise differences amongst the means of the diagnostic test scores. Bonferroni-corrected post-hoc follow-up tests were selected to control for Type-I error across the pair-wise comparisons.

One-way ANOVAs identified no significant differences amongst the different teaching pedagogy groups in the pre-test scores. However, at the post-test, one-way ANOVA followed up with Bonferroni t-tests showed all of the pair-wise differences to be significant. More specifically, the TSGW students displayed better scores on the diagnostic questions than their SDGW counterparts following the teaching intervention, whilst the WCTA students produced the lowest scores.

Accordingly, in response to the first research question, analysis of the pre- and post-diagnostic tests demonstrated greater improvement (as measured by the questions extracted from EPSE) in the group work students (SDGW and TSGW) relative to the students (WCTA) who received whole-class instruction. With regard to the second research question, the results revealed the group work students who received teacher guidance (TSGW) to have made even more progress than those in the self-directed group (SDGW).

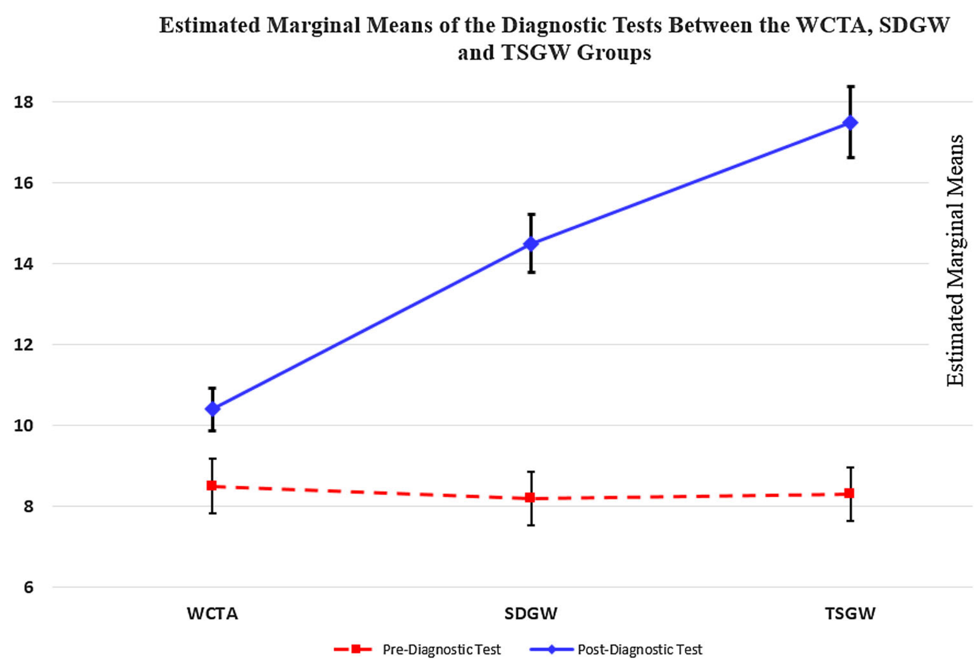

Figure 2. Results of the pre- and post-diagnostic tests extracted from EPSE.

Written responses to adapted TIMSS questions

Content analysis of students' written responses to the adapted TIMSS questions revealed that the TSGW students, in general, were better able to identify correct scientific concepts (and provide more detailed explanations) than their SDGW counterparts, whilst the responses of the WCTA students reflected the most misconceptions or naïve concepts. To afford a better understanding of how the different pedagogical groups attempted the questions, the following verbatim examples were extracted from the work of one student in each group for closer scrutiny.

Question A: What is the function of the battery in the circuit?

WCTA The function of the battery is to provide both energy and electrons to the circuit. The battery will give out an electron containing energy from the positive (+) side [terminal] and the electron will flow in the circuit and then will be eaten up by the light bulb finally

SDGW Battery provides energy and wire provides electrons to the circuit, respectively. The function of the battery is mainly an energy provider (to push the electrons) and also connecting the wire to make a complete circuit

TSGW Battery is the source of energy in the circuit. When the circuit is connected, the battery coverts stored chemical energy into electrical energy. The function of the battery is to push [move] electrons from the positive (+) end through the wire (which is a conductor) to the negative (−) end

These responses show that students in all three pedagogical groups accurately identified the battery as the source of energy in the circuit pictured. However, although the WCTA student recognised that electrons can flow through the circuit, he held the misconception that electrons are consumed by light bulbs. The SDGW student, in contrast, differentiated the main functions of battery and wire as being 'energy' and 'electron' providers, respectively. He also correctly stated that there must be a source of electrical energy and a complete circuit for electricity to flow. Finally, the TSGW student provided the most explicit explanation of the concept, clearly stating that the battery converts stored chemical energy into electrical energy, and the metal wire is regarded as a conductor in current electricity.

Question B: Light Bulbs A and B will be equally bright when connected to the circuit in parallel. Do you agree? Why or why not?

WCTA Yes, Light Bulbs A and B will have the same brightness. The brightness will be equally shared by the two bulbs when they are connected in parallel

SDGW I agree. Light Bulbs A and B will be equally bright because they are both connected to the battery directly

TSGW Yes, I agree. When the bulbs are connected in parallel, there are two identical paths connecting the bulbs and the battery directly. Therefore, the electrons can only pass through either path and both bulbs will get the same amount of energy

Similar to the previous question, all three students correctly answered that Light Bulbs A and B would be equally bright in the parallel circuit shown in Question B. However, the WCTA student expressed the mistaken impression that the brightness of the bulbs would be shared. Both the SDGW and TSGW students, in contrast, recognised that Light Bulbs A and B are connected to the battery directly (via different paths), implying that they have the same voltage level as the battery. The TSGW further elucidated the concept of a parallel circuit in his more comprehensive explanation. He explained that the bulbs are connected to the battery through two independent (and identical) paths in a parallel circuit, with the electrons able to pass through either path, giving the same amount of energy to the bulbs.

Question B (cont.): What are the effects on the battery when Light Bulb B is connected to the circuit in parallel, as shown in Figure B? Why?

WCTA No effect. Because the brightness and energy of Light Bulb A is shared by Light Bulb B and the total energy consumed in the circuit is the same as before
SDGW The battery needs more energy to light up the two bulbs
TSGW The energy consumed by the bulbs will become double and more energy will be drawn from the battery. The lifetime of the battery will reduce to half

The WCTA student demonstrated a similar misconception here to that above, stating that the energy would be shared between the two light bulbs if they were connected in parallel (similar to the 'shared brightness' misconception in the first part of Question B). The SDGW student correctly pointed out that the battery would need more energy to power two bulbs, whilst the TSGW student was more precise, stating that the total energy consumption would double, reducing the battery's lifetime by half.

Question C: A student has invented a 'lightning umbrella' that operates on the same principle as a lightning rod. Do you think that such an umbrella would protect its holder? Please explain your answer.

WCTA Yes, 'lightning umbrella' can protect the holder. In the event of a lightning strike, the people surrounding the 'lightning umbrella' may be struck but the holder can escape from the strike
SDGW No, holder of the 'lightning umbrella' will be the first one who gets the strike. The holder will become more dangerous than other people
TSGW 'Lightning umbrella' will not protect the holder because the principle of lightning rod is to attract lightning and then direct it via conductor to the Earth. Therefore, it protects buildings and structures. If I were the holder, I will consider giving the umbrella to one of my unpopular classmates and then I will stay away from him/her to protect myself

Interesting findings were obtained from students' responses to the question concerning the efficacy of a 'lightning umbrella', which evaluated their understanding of the principles of a lightning rod ('避雷針' in Chinese, which translates as 'escape-lightning rod') and its possible applications to other materials. It is amusing that the WCTA student believed that the holder would be protected if the lightning rod principle were applied to an umbrella. In contrast, the SDGW and TSGW students correctly inferred that a lightning umbrella would not only fail to protect its holder, but would actually attract rather than divert a lightning strike. The TSGW student was so confident in his answer that he humorously suggested he would offer the lightning umbrella to unpopular classmates and then steer clear of them to protect himself.

The foregoing sample responses to Questions A–C show that the SDGW and TSGW students outperformed their WTCA counterparts in distinguishing correct scientific concepts from naïve, common-sense beliefs. In addition, they also show that the TSGW students provided more precise explanations and detailed justifications to explicate the relevant concepts.

Audio-recordings of group discussions and individual presentations

To further illustrate students' joint construction of conceptual knowledge in the teaching intervention, several excerpts of the audio-recordings of student dialogues are presented in Appendix 3. These excerpts show how the students worked towards the science questions through individual and collaborative efforts and what they deemed to be appropriate evidence to support their scientific thinking. They were taken from recordings of a discussion on the topics stated in Questions A and B above.

In the first three extracts shown in Appendix 2 (i.e. Extracts 1A–1C), we can see the students presenting their preliminary ideas about or prior knowledge of the function of a battery in a circuit before receiving formal teaching in the 'Making Use of Electricity' unit. In Extract 1A, the WCTA student expresses his own view on the dual functions of the battery in supplying energy (Line 5) and providing free electrons (Line 4) to the circuit. Whilst he is correct about the first function (i.e. energy provider), the second is obviously a misconception, as it is the metal wire rather than the battery itself that provides most free electrons to the circuit. Further, the WCTA student appeared to have mixed up the concepts (or nature) of electrons and energy (Lines 4–6), as he believes that many electrons are consumed (i.e. 'eaten up' (Line 8)) when the light bulb is illuminated.

Extract 1B shows how the SDGW students worked collaboratively to tackle the question and illustrate their own viewpoints. In general, we can see the group as a whole, rather than as individual members, taking responsibility for drawing conclusions in the face of diverse opinions. In particular, after S3 presents his idea about the battery's role in providing energy to the circuit (Line 2), S5 queries him on how energy is carried to the light bulb (Lines 4–5). In fact, this issue sparks rather heated debate (Lines 7–12). In arguing about whether the battery provides (free) electrons to the circuit, the students are generally critical of one another's opinions and willing to express ideas, even when they conflict with their personal views, until deadlock is reached (Line 13). It is noteworthy that, through collaboration, the students are able to listen to and then challenge their classmates' opinions before reaching consensus (i.e. the battery completes the circuit), thereby substantiating their arguments with reasoned justifications (e.g. the metal wire provides electrons because it is a conductor of electricity) (Lines 8–9 and 15–16).

A notable observation from Extract 1C is the teacher's intervention in the TSGW group, which refocuses the discussion on the proffering of reasoned justifications when stalemate is reached. Tension builds up in the group after S3 vigorously seeks clarification of the opinions expressed by S1 and S2 (i.e. the battery provides energy that is then transferred to the light bulb through the metal wire (Lines 3 and 7)). Indeed, S3's vigorous pursuit of clarification not only results in discussion deadlock, but also unwittingly undermines S1's confidence in expressing his opinions (Lines 5–6). At this point, the teacher intervenes to ease the tension, and motivates the students to elaborate upon their ideas (i.e. to consider how the battery works from step by step (Line 10)) by offering them encouragement (e.g. 'Right, and then?' and 'Great! Marvellous!' (Lines 13 and 18)). In general, compared with their SDGW counterparts in Extract 1B, the TSGW students demonstrate superior ability to consider alternative (or counter) arguments in a dilemmatic situation (i.e. electrons versus a metal substance in transferring energy in a circuit (Lines 14–22)).

Extract 2A is taken from a presentation in which the WCTA student explains her ideas about the effects on a battery of two light bulbs being connected in parallel. It is important to note that this student has little chance of realising (let alone rectifying) her misunderstanding of science concepts (e.g. the sharing of 'brightness' between two light bulbs in a parallel circuit (Lines 8–10)) because she receives applause from her classmates despite it. In contrast, a key observation from the SDGW group is the dynamic aspect of students' joint construction of conceptual knowledge. In Extract 2B, we can see the students working together as a group and collaborating intensively to acquire better comprehension of the issue at hand (i.e. the effect on a battery when a parallel circuit is completed). That collaboration can be seen in the emergence of more concise and contextualised opinions

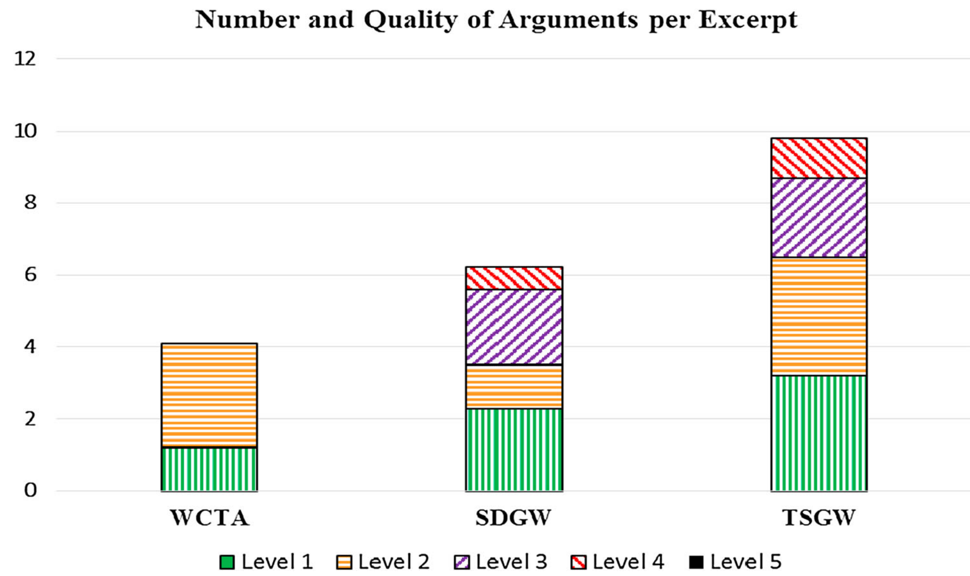

Figure 3. Results of argumentation quality analysed using the framework developed by Osborne et al. (2004).

(e.g. they (the two bulbs) take separate paths to reach the battery (Lines 9–10)), with each student taking his or her turn to speak. Finally, it should be noted that Extract 2C, in which teacher guidance is provided to the TSGW group (i.e. 'Let's consider the question from an "out-of-box" perspective' (Line 17)), highlights the important role of the teacher in giving prompts (i.e. Do you think greater energy consumption is the only effect on the battery? (Lines 17–18)) to induce further exchanges amongst students (and thus scaffold their learning), thereby supporting Vygotsky's (1978) view that teachers act as advanced, cognitively skilled partners in group work.

In summary, based on the qualitative analysis of the selected extracts presented above, in conjunction with Figure 3, which reports the statistical results on the quality of the arguments recorded in all excerpts ($N = 42$) from the WCTA, SDGW and TSGW groups,[4] it can be concluded that group work positively affects students' ability to perceive alternative science beliefs and identify misconceptions in secondary science classrooms. The advancement made by the TSGW students (relative to their SDGW peers) can be seen in their capacity to attempt a better understanding of their peers' opinions, support their claims with more reasoned justifications and consider different arguments in a dilemmatic situation.

Discussion and implications

In answer to the first research question concerning how group work affects junior secondary school students' science learning in Hong Kong, the results of our study show that the students who participated in group work (i.e. the SDGW and TSGW sub-groups) were better able to identify scientific concepts and general knowledge alternatives in the post-diagnostic test than those who learnt independently in a traditional setting (i.e.

WCTA control group). These students' relative superior performance accords with the belief that science inquiries, in general, are collaborative in nature (Johnson & Johnson, 1991; Rutherford & Ahlgren, 1990). The results are also in agreement with previous studies showing that group tasks induce a higher level of cognitive understanding and restructuring compared with conventional teaching practice (Chang & Barufaldi, 1999; Chang & Mao, 1999; Ertepinar & Geban, 1996; Saunders, 1992). Because cognitive growth requires students to consider issues from various viewpoints, argue intellectually and interact in social situations (Johnson & Johnson, 1991), cooperative activities provide science students with opportunities to take part in discussions that encourage conceptual change (Basili & Sanford, 1991), change that would not take place through individual tasks. New ideas and knowledge also stimulate students to think innovatively about problems and solutions (King, 2002) by challenging them and engaging them in the learning process (Cohen et al., 2002).

Further, in response to our second research question, the post-test results also attest to the supposition that students' science learning advances to a greater degree in teacher-supported (i.e. TSGW) than in self-directed group work (i.e. SDGW). Whilst the discrepancy in progression between the two experimental groups can be explained by the literature demonstrating that cooperative group work helps dismiss students' misconceptions in scientific discussions (Bilgin & Geban, 2006) and encourages interactive dialogues and reasoned claims through the use of open-ended questions (McNeill & Pimentel, 2010), rarely is the implicit participation of teachers who take up clarifying and directional roles addressed. In this regard, our study was informed by Vygotsky's (1978) ZPD framework, which contends that students learn from the example of higher achievers within their ZPD to develop the independent ability to handle tasks. Yet, because students usually do not challenge their teachers' credibility (in the Chinese classroom context of Hong Kong), and hence have less initiative to clarify ideas in their own words (Kewley, 1998), group work can only be made more effective when teachers maximise their role as facilitator and minimise their role as one-way lecturer. When teachers assist in the construction of knowledge rather than merely transmit knowledge (Tobin, Tippins, & Gallard, 1994), students, including gifted ones, will benefit from higher level reasoning and cognitive growth (Johnson & Johnson, 1991).

Contextually, teachers' role in the joint construction of knowledge was manifested in this study by their presence or absence in the transcribed interactions between students from the cooperating groups (i.e. TSGW and SDGW students). In Extract 1C, when the TSGW students are stuck in a deadlocked discussion, their teacher asks them to rethink the concept of a battery. Upon her affirmation at the first response received, more students begin to elaborate and give reasons (e.g. '[B]ecause metal is a conductor' and '[electrons] are responsible [for] transfer[ring] energy instead of the metal substance'). After her second instance of encouragement, the students arrive at the correct conclusion (i.e. '[electrons] convey energy from the battery to the bulb'). Although the teacher's remarks are brief in all instances, her assistance is timely and sufficient to help students to keep themselves on the right track. In contrast, although the SDGW students in Extract 1B are partly able to identify the scientific concepts required to answer the question and provide reasons for their arguments (e.g. 'I think electrons play an important role in carrying energy'; 'metal wire provides electrons to the circuit'; '[B]ecause it is a conductor of electricity'), they lack a trusted source to confirm or clarify their speculations, and are hence unable to carry on the discussion and reach real consensus when disagreements occur (e.g. 'Student 1 looks bewildered'; 'group members keep silent'). In addition, the absence of guidance from a teacher can also forestall further discussion and the generation of new ideas. For example, the students in Extract 2B are forced to abandon their exploration of their ideas because they cannot resolve the unknowns (e.g. 'I have no idea at this moment'; 'I think we can ask [the] teacher about this concept later'). The students in Extract 2C, in contrast, who are prompted by their teacher to probe further, are motivated to continue their exploration and move in a new direction with reference to their own experience (e.g. 'Do you think the battery will become overloaded? … I have [had that] experience before'; 'I have [had that] experience too'). This extract shows that a teacher's knowledge can serve as the implicit basis for the assistance needed by students, and, through guiding questions and affirmation, he or she can navigate students towards the right path to discover and build knowledge collaboratively using their own words.

The findings of this study highlight a pedagogical practice worthy of promotion in local science teaching at the secondary level. Traditional one-way teaching has been shown to be inadequate in stimulating students to consider a scientific concept from various perspectives, argue with reasons and articulate their learning results. One highlight of the four-phase teaching intervention adopted in this study is that students were asked not only to engage in peer-reviews and group debates (twice), but also to present their final answers by reaching consensus. Conventionally not required in science lessons, reaching consensus propels students towards raising and resolving questions in an interactive and reasoned manner, thereby strengthening their cognitive understanding and exploration of a theory. To maximise its learning impact, group work pedagogy should be applied in science classrooms with tasks deliberately chosen for discussion purposes. For instance, teachers are encouraged to adopt a set of questions designed with a lead that allows students to agree or disagree with a scientific preconception, and then to afford them the room to debate and participate in in-depth discussions. In this way, students can be driven to learn actively and to exercise their full potential, not to mention being rescued from the rote learning that prevails in Hong Kong education, where students customarily receive information without fully comprehending it.

In addition, as stated in the Background section of this paper, the under-exploited practice of group work in secondary schools may offer a more empirical and constructive explanation for the declining TIMSS results observed in local students as they transition from primary to secondary education. Rather than interpreting that decline as a sign of discontinued growth in science learning, educators would be advised to recognise it as a signal of the need to expand collaborative learning to the post-primary level. As the progressive improvement of students subject to different teaching practices in this study has shown, students' capacity can be unlocked through TSGW. It is thus hoped that the wider practice of this approach in Hong Kong will push students towards more consistent achievements in science subjects and gradually narrow the discrepancy between junior and senior learners.

Notes

1. The diagnostic questions were extracted from EPSE Project 1 (Sample Diagnostic Questions – Set 3), which evaluates students' understanding of circuit behaviour.
2. Sample questions are shown in Appendix 1.

3. The effect size calculations in the current study were based on partial-η^2 values (Cohen, 1973). Cohen (1988) provided estimates of what constitutes a small (0.01), medium (0.06) and large (0.14) effect for partial η^2.
4. Due to space limitations, analysis of the quality of the arguments in some of the sample excerpts (i.e. Extracts 1A–1C) is given in Appendix 2.

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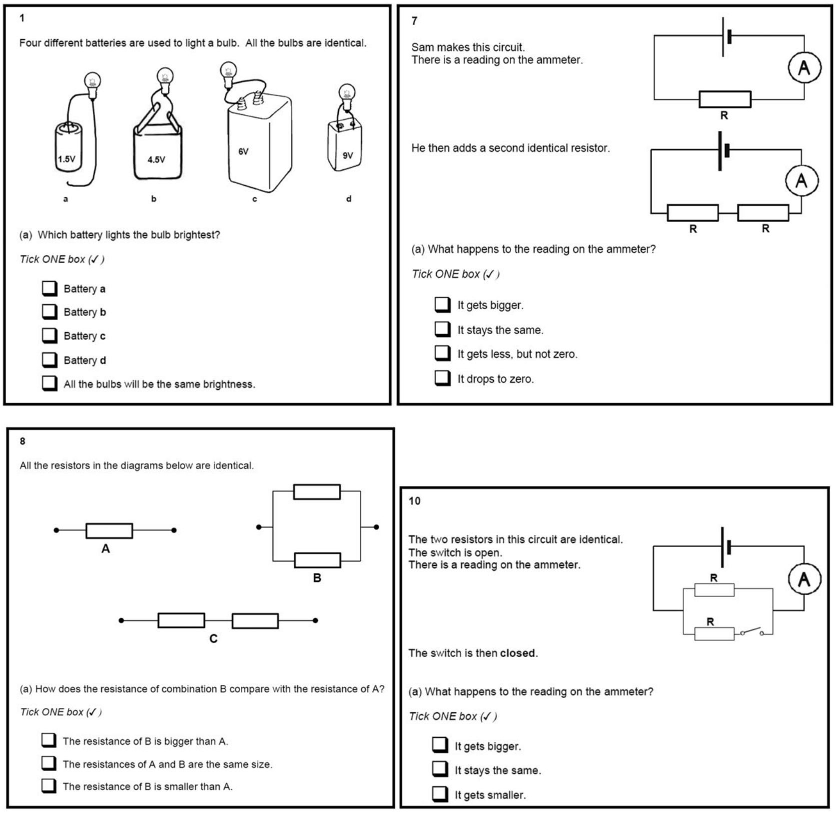
Appendix 1. Sample diagnostic questions (extracted from EPSE Project 1: Set 3, Circuit Behaviour)



Appendix 2. Descriptions of the analysis of argumentation quality (Extracts 1A–1C)

Extract 1A	Assessment of the argumentation quality in Extract 1A using the Erduran et al. (2004) framework identified three Level 2 and one Level 1 arguments. Whilst the student offers 'backing' (i.e. through explanations (see Lines 3–8)) for his ideas on 'nucleus', 'engine' and the 'positive side of the battery' (arguments that were classified as Level 2), he simply states his opinion that the bulb converts electrons into light and heat without providing any reasons or justification (this argument was classified as Level 1) during his presentation (see Lines 9–10)
Extract 1B	Two Level 1, one Level 2 and two Level 3 arguments were identified. Whilst S3 and S1 make arguments that contain simple claims (i.e. the battery provides energy and electrons, respectively (see Lines 2 and 7)), S5 supports her argument with non-spurious (relatively informal) evidence (i.e. the positive and negative signs of the battery (Line 10))
Extract 1C	Three Level 1, three Level 2 and two Level 3 arguments were identified, in all of which the students progressively produce more reasoned and justified arguments near the later stage of the discussion and become more critical in an attempt to better understand their peers (Lines 14–22)

Appendix 3. Sample extracts of audio-recordings of student dialogues

Extract 1A – WCTA Group (**S** = Student)

		Line	Arg.
S	Hello, everyone! I am going to present my view on the question of 'What is the function of the battery in	1	
	the circuit?'	2	
S	Actually, I think battery works like a sort of 'nucleus' and 'engine' in a circuit	3	
S	As a nucleus, the battery gives out a huge amount of electrons which can move freely in the wire.	4	L2
	Moreover, as an engine, it provides energy to supply forces to push the electrons moving around the	5	L2
	circuit	6	
S	Positive side (+) represents the side which has a higher number of electrons because many electrons are	7	L2
	eaten up by the bulb and only some can return to the negative side (–)	8	
S	The light bulb makes use of the electrons and converts them into light and heat	9	L1
S	Thanks for listening to my presentation [the student's classmates applaud]	10	

Extract 1B – SDGW Group (**S** = Student)

S4	Let's move on to talk about the function of the battery. S3, do you have any ideas?	1	
S3	I have no ideas indeed. However, I guess that the battery provides energy to the bulb. Otherwise, how can	2	L1
	the circuit make the bulb light up?	3	
S5	I agree. But how can the battery carries energy to the light bulb? I think electrons play an important role in	4	
	carrying energy	5	
	… [Student 1 nods his head to show support] …	6	
S1	Yes, therefore, I think battery also provides electrons to the circuit	7	L1
S2	No, I don't think so. I think the metal wire provides electrons to the circuit. Because it is a conductor of	8	L3
	electricity [Student 1 looks bewildered]	9	
S5	Um … you are probably right, but … there is a positive and a negative sign in the battery. I guess that they	10	L2
	represent the high and low numbers of electrons stored in the two sides	11	
S2	I disagree. The two signs represent the high and low levels of energy stored in the battery	12	L3
	… [other group members remain silent, and deadlock persists for five seconds] …	13	
S4	Anyway, the battery not just provides energy and electrons, but also completes the circuit	14	
S3	Right, the battery converts an open circuit into a closed circuit, do you all agree?	15	
	… [other group members show their agreement] …	16	

Extract 1C – TSGW Group (**S** = Student; **T** = Teacher)

S2	I think that the battery is the source of energy in the circuit. Like the sun is the source of energy in the solar	1	L1
	system	2	
S1	Yes, I agree. The energy from the battery makes the bulb lights up	3	L1
S3	How to make the bulb lights up?	4	
S1:	Um … [Student 1 appears surprised at being asked to explain his answer, and struggles for a response]	5	
		6	
S2	I think the energy is transferred from the battery to the bulb through the metal wire, right?	7	L1
S3	Yes, I know, but my question is how to make the bulb lights up	8	
	… [tension builds up amongst the group members, and stalemate is reached] …	9	
T	Okay, boys and girls, try to consider how the battery works from step by step	10	
S1:	Yes, I think when the circuit is completed, the chemical energy in the battery is converted into electrical	11	
	energy. This is the first step	12	L2
T	Right, and then?	13	
S2	Then the electrical energy is transferred through the metal wire to the light bulb. Because metal is a	14	L2
	conductor. I think it is the second step	15	
S4	But I think electrons can move freely in the wire. They are responsible to transfer energy instead of the	16	L3
	metal substance, right?	17	
T	Great! Marvellous! Come on, continue.	18	
S1	I think the electrical energy carried by electrons is changed into heat and light energy when the electrons	19	L2
	reached the bulb, since electrons can move in the wire	20	
S2	Yes, but I argue that the electrons are just like carriers which convey energy from the battery to the bulb	21	L3
	and not to be consumed when the circuit is connected	22	

Extract 2A – WCTA Group (S = Student)

		Line	Arg.
S	Good morning! I would like to share my thoughts regarding the effects on the battery when Light Bulbs	1	
	A and B are connected to the circuit in parallel	2	
S	I believe that there will be no effect on the battery if the circuit is connected	3	
S	This is because Bulb B will not draw extra energy from the battery although it is connected to Bulb A in	4	L2
	parallel	5	

(*Continued*)

Appendix 3. Continued.

	Extract 2A – WCTA Group (S = Student)	Arg.
S	Since there is just one battery (with two cells), the energy consumption should be constant no matter how many light bulbs are connected to the circuit	L2
S	In this case, therefore, the energy and brightness of Bulb A will be equally shared with Bulb B. Unless one more battery is added, otherwise Bulb A will become dimmer compared to its initial brightness	L1
S	Moreover, the only difference between the parallel and series circuit is that if one bulb is broken, the other bulb in the former circuit can still operates, but cannot do so in the latter circuit	
S	Thanks for listening to my presentation [the student's classmates applaud]	

Extract 2B – SDGW Group (S = Student)

S1	Let's talk about the effects on the battery shown in Figure B. I believe that there will be no effect on the battery if Light Bulbs A and B are connect in parallel to the circuit	L1
S2	Why?	
S1	Because the battery is kept no change and the two cells in the battery are connected in series. Therefore, the energy given out from the battery will always be the same	L2
S4	I disagree. If there are many light bulbs, let's say one hundred, connected to the circuit in parallel, how can the battery support all the bulbs without giving out more power?	L4
S2	Yes, I agree. I think the battery provides more energy to the circuit in order to light up the two bulbs. Because when the two bulbs are connected in parallel, they have separate paths to reach the battery. In this case, more energy is given out from the battery	L3
S3	I think this idea makes sense	
S2	Okay, I think we have reached a consensus. S1, do you agree with us now? [Student 1 nods his head]	
S3	However, I think Student 1's idea about the connection of cells [series vs. parallel] in the battery is inspiring. I agree that the connection actually can affect the energy output of the battery. However, I have no idea at this moment	L1
S3	Yes, I agree. I think we can ask teacher about this concept later [the student's group mates express agreement]	

Extract 2C – TSGW Group (S = Student; T = Teacher)

S2	Let's go to the next question regarding the impact on the battery. Any ideas?	
S1:	As we have just agreed that Light Bulbs A and B will be equally bright if both are connected in parallel and electrons can only pass through either path, the battery definitely needs more energy to support the two bulbs	L2
S3	Yes, I agree. But how much 'extra' energy needs to support the two bulbs?	
S1	I think it is difficult to measure and quantify the extra energy	
S4	I disagree. If the extra energy cannot be measured, we don't need to pay higher fees in our electricity bills after we turned on more lights at home. I think we have several ways to find out the extra energy. First, we can use instruments (e.g. Joule meter) to measure the energy output of the battery. Second, we can use the same instrument to measure the energy input of the light bulb. Finally, we can consider the lifetime of the battery	L4, L3
S2	Yes, in this case, I think we don't need a precise measurement but can predict that the energy consumption will become double and lifetime of the battery will reduce to half	L2
S3	Yes, I agree. Let's write our answers on the question paper. … [The discussion seems to end in consensus, and the students start to write their answers down individually.] …	
T	Hey, Boys and girls. Let's consider the question from an 'out-of-box' perspective. Do you think a higher energy consumption is the only effect on the battery?	
S3	Um …	
S1	Do you think the battery will become 'overloaded' and give out a certain amount of heat? I have this experience before. After I played my toy, a remote control car, for a while, the battery became a bit warm	L2
T	Yes	
S4	I have this experience too.	
	… [The discussion continues in a new direction] …	