Chapter 15
Identifying Pivotal Contributions for Group Progressive Inquiry in a Multimodal Interaction Environment

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Introduction

Inquiry learning has its origins in the practices of scientific inquiry and focuses on posing questions, gathering and analyzing data, and constructing evidence-based explanations and arguments. Hakkarainen (2003) proposes an inquiry pedagogical approach termed as "progressive inquiry" for young learners in learning science. Progressive inquiry is a progressive and cyclic process consisting of six interacting elements that guide learners to (a) systematically generate their own research questions, (b) construct their own intuitive working theories, (c) critically evaluate various intuitive conceptions generated, (d) search for new scientific information, (e) engage in progressive generation of subordinate questions, and (f) build new working theories as the inquiry process continues. The process is not linear and may not involve all the components in each learning cycle.

From the knowledge advancement and creativity perspective, Hakkarainen and Paavola (2009) posit that in progressive inquiry, a focus should be placed on how students collaboratively organize their activities for developing something new. Rather than focusing solely on idea improvement, they propose using a trialogical approach to guide the examination of learning. The trialogical approach emphasizes the collaborative development of mediating objects or artifacts rather than monologues within a mind (the acquisition view) or dialogues between minds (the participation view). The aim of the inquiry is to progressively refine concrete knowledge artifacts or to further elaborate upon a shared object.

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There are various ways to examine collaborative knowledge advancement in inquiry learning in the existing literature (Stahl, Koschmann, & Suthers, 2006). Some researchers examined collaborative process at both the individual and group levels (e.g., Arvaja, Salovaara, Häkkinen, & Järvelä, 2007). Other studies have examined collaboration as knowledge convergence, which focuses on individual contributions independently of each other (e.g., Weinberger, Stegmann, & Fischer, 2007). However, Stahl (2002) posits that to understand collaborative learning, it is important to understand how groups work together to make sense of the problem inquiry situations.

In this paper, we explore a trialogical approach that focuses on concrete objects in mediating collaboration to examine how progressive inquiry in science learning happened in one target group of a grade 5 class supported by Group Scribbles (GS)—a collaborative technology (Chen, Looi, & Tan, 2010). We are interested in investigating how a group of students working as a group co-constructed shared artifacts in a science lesson on the topic of electricity via different modes of interactions. To achieve these aims, uptake analysis (Suthers, Dwyer, Medina, & Vatrapu, 2010) is adopted to discover the meaning-making process in the group cognition, leading to progressive inquiry in science learning. We extend uptake analysis to explore the notions of different types of uptakes in a multimodal environment setup comprising verbal, online, and experimental science practice interactions. We also further explicate the notion of pivotal contributions (a contribution that plays the role of shifting the direction of the subsequent events seamlessly or abruptly) by identifying them in the dataset and explore how these contributions shape the direction of the group inquiry productively. This chapter constitutes our contribution to productive multivocality in the analysis of collaborative learning (Suthers et al., 2011).

The research context, the participants, and the data sources are covered in the data chapter (Chen & Looi, Chap. 14, this volume). The organization of the chapter is as follows: we first discuss the analytic approach and how each contribution is coded and categorized and thereafter present the transcript of the dataset. We next identify pivotal contributions via transitional stages of interactions that influence the course of inquiry as well as uptake paths for group progressive inquiry. The chapter ends with a discussion of the results.

Research Methods for Analyzing Progressive Inquiry in GS

Data Sources

To understand the group progressive inquiry process, we focused on three data sources: speech and gesture interactions, artifacts in GS, and captures of experimental practices, as described in Table 15.1.

Table 15.1 Descriptions of data sources

No.	Data sources	Description
1	Speech and gesture interactions	Verbal interactions consisting of conversations and gestures between students and between the student(s) and the teacher in the course of collaborative progressive inquiry
2	Artifacts in GS	Data related to the posting or the editing of a GS note on the private board of individual students or on their group board in GS
3	Captures of experimental practices	Data related to the captures of hands-on experiment of connecting the circuit and the outcome of experiment (trial–error actions)

Uptake Analysis

One approach to analyzing collaborative interactions is sequential analysis deployed to examine the meaning of an act or an utterance as a function of its context of the prior sequence of acts and utterances. To understand collaborative interactions, conversation analysis (Sacks, 1992) and video analysis (Koschmann, Stahl, & Zemel, 2005) are adopted, focusing on turns or adjacency pairs to produce interpretive results (Stahl et al., 2006). However, analysis based on turn-taking or adjacency pairs is appropriate neither for synchronous nor for non-synchronous online communications in which contributions may be produced in parallel and are persistent due to the nature of the collaborative technology. We cannot reduce the complexity of the analysis by shrinking the time window to search for relevance relations only in adjacent contributions. Any previous contribution produced on the technology may be taken up again in later nonadjacent contributions (Suthers, 2006; Wee & Looi, 2009).

In addition, in many cases, multiple media are involved and the data are collected in a variety of formats; we need to transcribe and examine the data for collaborative interactions, which may not be apparent upon inspection, being distributed across these different media (Suthers et al., 2010). To address such issues, Suthers (2006) proposes the concept of "information uptake" which refers to "the event of a participant doing something with previously expressed information"; and this previously expressed information is termed as a previous contribution. In later definition of uptake, Suthers et al. (2010) posit, "Uptake is present when a participant takes aspects of prior events as having relevance for ongoing activity" (p. 5). Uptake can add to or modify the prior contributions or relate it to new contributions. It can take up a participant's own prior contribution as well as those of others. By identifying both types of uptakes, it is possible for researchers to characterize the mixture of intrasubjective and intersubjective knowledge constructions (Suthers, 2006). It is noted that a prior contribution refers not only to a relevant immediately adjacent event but also to relevant nonadjacent events that have "logical adjacency" (Stahl, 2006, p. 91).

In our study, we attempt to examine student collaborative meaning making through the evolvement of artifacts created in GS in multimodal interactions among speech, artifacts created in GS, and captures of experimental practices, using a trialogical approach. Due to the complexity of the interactions, we adopt uptake analysis method to discover patterns of the collaborative activities. Building on the concept of "uptake," we define an "uptake" as the event of a participant doing something with previous contribution(s) by the student, a group, or the teacher. Doing something in our study means the process of verbal communication, artifact creation in GS, and experiments in lighting up bulbs in the course of progressive inquiry. The uptake analysis does not provide explanations or make predictions of the relationships. Uptake is treated as "a fundamental building block of interaction, and the basis for construing interaction as an object of study" (Suthers et al., 2010, p. 7).

We attempted to address three questions in the analysis:

1. What are the types of uptake in the interactions between speech interactions, artifacts, and experimental practices?
2. How are pivotal contributions identified across the interactions between speech interactions, artifacts, and experimental practices in the uptake paths?
3. How do the uptake paths support progressive inquiry adopting a trialogical approach?

We next summarize our theoretical framework and methodology through a discussion of five specific dimensions (cf. Chap. 2).

Theoretical Assumptions

In the collaborative learning environment supported by GS, there are multiple media that mediate students' progressive inquiry, which is represented at two levels:

1. The first level (uptake analysis): It is assumed that uptake happens in the learning environment when a participant takes aspects of prior events as having relevance for ongoing activity. Progressive inquiry can be examined through pivotal contributions marked out at different stages in the uptake paths.
2. The second level (a trialogical approach): Tracing the development of the students' shared artifacts in GS helps make the progressive inquiry "materialized."

Purpose of the Analysis

The purposes of using uptake analysis are:

1. To interpret pivotal contributions in the context of the uptake diagram for progressive inquiry.
2. To interpret how the uptake paths support group progressive inquiry by focusing on visualizing the evolving process of the shared group artifacts.

Unit of Interaction

The data are sequential traces of contributions (data belonging to the same event was grouped together and coded as a contribution if they manifest a single interactional move or behavior). The unit of interaction is "uptake" which presents when a participant takes aspects of prior events as having relevance for ongoing activity.

Representations of Data and Analyses: Coding Contributions and Uptakes

For representing the data and the analysis, we first studied video recordings (all around 30 min) in the electricity lesson (one target group video recording, four individual Morae video recordings, and one class video recording). Secondly, we discussed segmentation of the video data for the uptake analysis. Thirdly, we chose the group video clip between the timing 00:12:15 and 00:16:16 as our object of analysis because we concurred that interesting interactions happened in this segment. We then synchronized what happened during this time period with the other video clips accordingly.

Fourthly, to do the data analysis, we adopted the family of methods loosely classified as exploratory sequential data analysis (Sanderson & Fisher, 1994), especially interaction analysis (Jordan & Henderson, 1995), to identify ethnographic chunks (easily identifiable behavioral units) first and then to transform the data into representations that are more suitable for analytic interpretation (Suthers et al., 2010). One of the authors transcribed the video clips based on the chunking units of: speech communication artifacts created in GS and captures of experimental practices that were represented using screenshots and were logged together with the transcribed verbal text in a sequential order. Another author read the data logs, identified obscure transcriptions, and suggested going back to the raw data for re-transcription of those parts.

Fifthly, the transcribed data were coded and analyzed line by line along with the screenshots of the artifacts in GS and experiments. Data belonging to the same observable action was grouped together and coded as a contribution with an assigned contribution number. Each contribution was numbered in a sequential order chronologically. The numbered contributions can be (a) an individual utterance; (b) an act of artifact creation in GS and experiments; or (c) sets of sequential utterances or acts that form a single interactional move by one participant or the group.

Next, in order to distinguish the three forms of contributions by different participants, we coded the contributions in four ways: (a) To represent a specific participant's utterance, we chose to use the first capitalized letter of the contributing participant's name in front of the numbered contribution. For example, J2 represents the contribution from the participant Joel, which is the second coded contribution in sequence. (b) To represent an act of artifact creation in GS, we chose to use the first capitalized letter of the contributing participant's name, followed by a small letter "g" in front of the numbered contribution. For example, Bg17 represents the artifact created in GS from the participant Bruno that is the 17th coded contribution in sequence. (c) To represent an act of experimental practice, we chose to use capitalized "G" to represent the group doing the experiment, followed by a small letter "e" to represent experimental practice. For example, Ge22 represents the experiment conducted by the group that is the 22nd coded contribution in sequence. (d) To represent special coded contributions such as when two participants were involved in creating the artifacts, we used artifact coding method and used a plus to combine the two in front of the numbered contribution. For example, "Ag + Bg26" represents artifact creation by Agnes and Bruno, which is the 26th coded contribution in sequence. A similar coding method was applied to the coding of an experimental practice. Finally we triangulated the coding and presented the contributions chronologically (see Appendix I). Referring to the coded contributions and their related transcripts, we identified uptake relationships. We identified the contributions that added to or modified the previous contributions to a new form. We then identified whether the interaction relationships between contributions was intrasubjective—a participant did an uptake on his/her own contribution(s), or intersubjective—a participant did an uptake on others'/group's prior contribution(s). These contributions had "logical adjacency" rather than ordinary adjacent pairs. We generated uptake diagram using arrows to demonstrate uptake relationships (Suthers, 2006). The results of the uptake analysis were triangulated between two researchers.

Manipulations

After the phase of coding to identify contributions in sequence and uptakes, two other phases were involved in the data analysis: identifying pivotal contributions via transitional stages of the interactions and identifying uptake paths for group progressive inquiry.

Identifying Pivotal Contributions via Transitional Stages of the Interactions

We define a pivotal contribution as a contribution that plays the role of shifting the direction of the subsequent events (contributions) seamlessly or abruptly through uptake between the subsequent event (contribution) and the transitional stage. Identifying transitional stages goes hand in hand with identifying pivotal contributions.

Jordan and Henderson (1995) posit that events of any duration are always *segmented* in some way. They stated that analysts are interested in the ways in which participants make the internal structure of the events visible to themselves and to each other and are interested in how they can present in some sense that they have reached a segment boundary in the work and that the next stretch of interaction will be of a different character. Thus, a segment boundary is the place where a transition occurs from one segment of an event to another indicated by a shift in activity. In some cases, the students are aware of the sequence of the learning activities and the problems they need to solve in general, although how they are involved in the activities and how they solve the problems in real learning situations may vary. When the students finish doing something and something new is starting, it is considered a smooth transition from one stage to another. Such a transition was termed "a seamless transition" (Jordan & Henderson, 1995). In some cases, the transition from one stage to another is not smooth. It is stopped abruptly and shifts to a new stage, which is termed as "abrupt transition" by Wee and Looi (2009).

In our analysis, we adopted the methods of segmenting a series of events in the form of coded contributions (the utterances, artifact creation, and experimental practices) into different stages based on the segmented transitional boundaries to trace the progressive inquiry. Both seamless and abrupt transitions were identified in the uptake graph. For example, contributions O1, J2, and B3 (see Appendix) were a series of events about proposing, praising, and accepting the idea of using two batteries to light a bulb. S4 proposes doing an experiment on the idea, and from Je5, activity shifted to doing the experiment. Thus the transitional boundary is between S4 and Je5, S4 is a pivotal contribution, and the transition is smooth and seamless. From contributions Je5 to J9, the events were concerned with students doing an experiment successfully with verbal utterances. S10 raised a new question of trying a new experiment, so here is a transitional boundary between J9 and S10 and S10 is another pivotal contribution. But this approach suggested by S10 failed to be further explored, as at this moment, the teacher (T12) facilitated the students to represent their understandings gained from speech interactions and experimental practices onto the GS space. T12's utterance of "No draft, no draft [on the group board]. Then people will look at a blank board" caused the abrupt shift of the event from doing and discussing about the experiments to B13's working on drawing the artifact in GS. Thus one more transitional boundary lies between T12 and B13; and the transition is abrupt. T12 is the real subsequent pivotal contribution after S4. To distinguish between successfully and unsuccessfully explored pivotal contributions, we named them manifested (the former) and latent (the latter) pivotal contribution, respectively, in this paper. S4 and T12 are *manifested pivotal contributions*, and S10 is a *latent pivotal contribution*.

By identifying the uptakes, transitional stages, and pivotal contributions of uptake in a graph representing interaction process, we are able to discern uptake paths. These paths are helpful for us to make interpretations of students' group meaning-making process of progressive inquiry illustrated in the next section.

Identifying Uptake Paths for Group Progressive Inquiry

This phase of uptake analysis focused on (a) connecting interactional relationships to identify uptake paths for the group progressive inquiry and (b) providing evidence that supported group knowledge co-construction in the inquiry process.

We did coding of video data and produced the transcript in Appendix I. We distinguished the different modalities of the contributions comprising conversations and gestures; GS artifacts being created, edited, or moved about; and the state of the students' trial–error experiments as represented by the still shots extracted from the videos. For some of the students' trial–error experiments, because there were contributions in which the view of the experimental circuits was blocked or occluded, we were not able to observe what they were working on. In such situations, we relied on verbal utterances and the GS artifacts to infer what might be going on.

Results

Types of Uptake

We used symbols to visualize the flow of uptake in the progressive inquiry (see Fig. 15.1). Different modalities of contributions are represented in different shapes: a square represents a contribution of a verbal utterance; a circle represents an artifact creation in GS; and a triangle represents a contribution of an experiment. The dotted line refers to intrasubjective uptake, and the solid line refers intersubjective uptake.

Table 15.2 shows two dimensions of contributions in terms of uptakes that are intrasubjective or intersubjective (SS stands for student–student, and ST stands for student–teacher) and the modalities. According to the table, there are a total of 27 ($3 \times 9 = 27$) types of uptake. Among them, the percentage of speech-initiated uptakes (42.3 %) is higher than that of the other two modalities initiated uptakes (30.8 and 26.9 %, respectively). Nevertheless, the difference among different modalities is not huge. This means that every modality of interaction is important for the emergence of uptake.

We also counted the number of the various uptakes between the same participant, and between different participants. It was noted that the majority of the interactions ($61.5 + 23.1 = 84.6$ %) happened between different participants, and the interactions between the same participants (15.4 %) were identified mainly from Bruno and Agnes. This indicates that the two students were more engaged in reflection and evaluation of their working theories. The majority of intrasubjective uptakes happened via GS artifacts. That means Bruno and Agnes were leading the role of externalizing their understandings by means of working artifacts in GS.

Pivotal Contributions in the Progressive Inquiry

We seek to identify the pivotal contributions via examining transitional stages of the interactions. In our study, we identify seven pivotal contributions in the

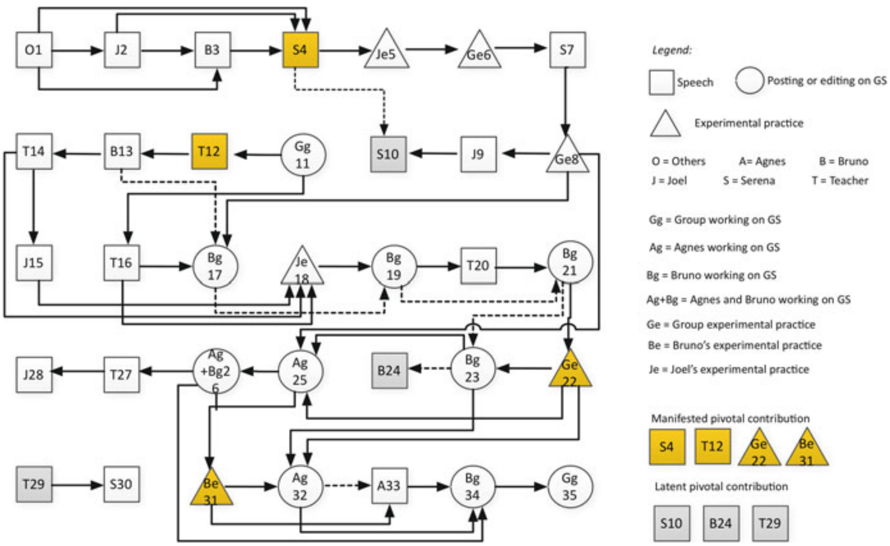

Fig. 15.1 The uptake diagram with pivotal contributions

uptake diagram (see Fig. 15.1) in different transitional stages. Among the pivotal contributions, four are manifested pivotal contributions S4, T12, Ge22, and Be31, and three are latent pivotal contributions S10, B24, and T29. Linking to the structural features of the graph, we describe how each of the pivotal contributions led to significant shifts of the progressive inquiry in understanding the ways to light one or more bulbs using one or more batteries and how to conceptualize a closed electric circuit comprising batteries and bulbs.

Manifested pivotal contribution S4: From inspecting Je5, Ge6, and Ge8 as a path of experimental practice and the preceding event S4 as a high-degree node (that is, one with a good number of incoming and outgoing uptakes), S4 is a candidate for a pivotal contribution. In the uptake path (O1–S4), although a student from another group (O1) suggested that the group tried to light a bulb using two batteries, which was appreciated by Joel (J2) and Bruno (B3), it was Serena (S4) who set up the question for the group to connect a circuit to light a bulb using two batteries for the group using both verbal language and gestures. This sparked the group's (J2, B3, and S4) interest in exploring new scientific information through a new experiment. Thus, Serena (S4) contributed to the group inquiry path shift from the previous experiment of using one battery to light a bulb to a new experiment of using two batteries to light a bulb.

Latent pivotal contribution S10: After completing the experiment of lighting a bulb using two batteries, instead of reflecting and externalizing their intuitive working theories by drawing their understandings of the closed electrical circuit in GS, Serena (S10) raised a new question of trying to understand how to light two bulbs

Table 15.2 Types of uptake and its percentages

		Speech initiated			Artifacts initiated			Hands-on initiated			
		to F2F	to Artifact	to Hands-on	to Artifact	to F2F	to Hands-on	to Hands-on	to F2F	to Artifact	Sum (%)
Intrasubjective		1	1	1	3	2	0	0	0	0	8 (15.4)
Intersubjective	SS	8	1	2	6	0	3	1	3	8	32 (61.5)
	ST	5	2	1	0	2	0	0	2	0	12 (23.1)
Sum (%)		14 (26.9)	4 (7.7)	4 (7.7)	9 (17.3)	4 (7.7)	3 (5.8)	1 (1.9)	5 (9.6)	8 (15.4)	52 (100)
Total (%)		22 (42.3)			16 (30.8)			14 (26.9)			

using two batteries. At this critical moment, the teacher (T12) facilitated the students to represent their understandings gained from speech interaction and experimental practice onto the GS space. In the uptake diagram, we can see a breakpoint between S10 and subsequent contribution. Thus here S10 is a latent pivotal contribution which fails to be further explored.

Manifested pivotal contribution T12: In the uptake path (Gg11–Bg21), the teacher's facilitation and orchestration (T12) was picked up by Bruno (B13) and was crucial to change the direction of the group inquiry path from trying to do a new experiment to reflecting and conceptualizing their working theories of how to light a bulb and the mechanism of the circuit. So Bruno (B13) began to draw the circuit in GS. While Bruno (B13) was drawing, the teacher (T14) reminded him, "Where are the two batteries?" which indicated that Bruno should show the circuit of connecting two batteries to light the bulb. This further fostered the group to do the experiment and draw their working theories by Bruno (B17) gained from the experimental practice.

Manifested pivotal contribution Ge22: In the uptake path (Ge22–J29), before posting their conceptualized working theories of the mechanism of the closed electrical circuit in a graph on the private board to the group board in GS, the group (Ge22) did the hands-on experiment again to evaluate their intuitive understanding. After the evaluation, Bruno seemed confident that his drawing of the circuit (Bg21) was "correct" after further checking the experiment results by the group (Ge22) and posted it to the group board (Bg23). Ge22 is pivotal as it helped Bruno confirm his conceptualization of the circuit before initiating further inquiries. Then, Bruno (B24) proposed to try to light three bulbs. At this moment, it was Agnes (A25) who identified the problem in the drawing by uptaking the information from previous contributions Ge8, Ge22, and Bg23 and began to externalize her understanding of the working theories by starting to draw another circuit in GS. Bruno and Agnes (Ag + Bg26) began to work together on the evaluating, reflecting, and revising their group working theory.

Latent pivotal contribution B24: When Bruno (B24) proposed to try to use three bulbs, his proposal was not answered. Instead, students zeroed in on evaluating and reflecting their temporal inscriptional artifact.

Latent pivotal contribution T29: While Agnes and Bruno (Ag + Bg26) were working in GS to conceptualize their new understanding of drawing the circuit, the teacher (T29) asked the students to stop working on their own group board and to visit other group boards. This was only picked by Serena (S30) but failed to be continued.

Manifested pivotal contribution Be31: In the uptake path (Be31–Bg35), while referring to Agnes' (Ag25) drawing on his private board, Bruno (Be31) began to explore new information further through experiment in order to externalize his understanding. The new experimental practice transformed Bruno's understanding. So Be31 played a pivotal role in making Bruno accept Agnes' (A32 and A33) advice on deleting the wrong drawing and completing a correct one (Bg34) and posting it (Bg35) to the group board. This contributed to Bruno's success in externalizing the working theories of the closed electric circuit to light a bulb using two batteries.

Agnes and Bruno manifested group cognition in this process that was made possible because of the mediation of F2F, online, and experimental practices.

Uptake Paths for the Progressive Inquiry

The pivotal contributions marked out different stages of progressive inquiry as distilled out in the uptake paths described below:

Stage 1: Generate students' own research questions (from O1 to S4): A student from another group (O1) suggested to Serena (S4) to try to light the bulb using two batteries (after the group successfully lighted a bulb using one battery). This information was overheard by Joel (J2) and Bruno (B3). Serena (S4) had an uptake on the information from O1, J2, and B3 and set up the question of trying two batteries to light a bulb based on their intuitive working theories of how to connect the light bulb using one battery. S4, the manifested pivotal contribution, helped the group to shift from proposing the inquiry problem to the problem experimentation seamlessly.

Stage 2: Search for scientific information through experimentation (from Je5 to S10): The group, initiated by Joel (Je5), began to search new ways through experimentation to connect the circuit with the bulb and two batteries. They connected the bulb but failed in lighting the bulb in their first group attempt (Ge6). It was Serena (S7) who found the problem ("wrong side" was taken up by the group). The group quickly succeeded in lighting the bulb in their second attempt (G8). Serena then (S10) had a new proposal but was not adopted by the group.

Stage 3: Construct their own intuitive working theories of how to light the bulb and draw the bulb circuit (from Gg11 to Bg21): After successfully connecting the bulb with the batteries, the group did not externalize their working theories onto the group board (Gg11). It was the teacher (T12) who advised the group in time to show their co-constructed understanding of the bulb circuit through experiment on the group board. This information enabled an uptake by Bruno (B13) which led to the group's later work on externalizing their understanding of how to connect two batteries to light a bulb. In this stage of progressive inquiry, the manifested pivotal contribution T12 helped facilitate students' inquiry to a new height—to conceptualize their working theories in lighting up the bulbs. T12 introduced an abrupt transition of the group's inquiry process from doing further experimentation to conceptualizing the group working theories.

Stage 4: Evaluate different intuitive understandings of the bulb circuit (from Ge22 to T29): Before posting the drawing of the bulb circuit to the group board, the group (Ge22) connected the light bulb again for the evaluation of the group's intuitive working theories on bulb circuit. Bruno (Bg23) checked how the bulb was lighted using two batteries again and then posted the drawing of the circuit from his private board to the group board. Bruno's proposal (B24) of testing three bulbs was not picked up. Instead, Agnes (Ag25) began to draw the circuit on Bruno's private board again to explicate whether Bg23's bulb circuit was correct. This triggered Bruno (Ag + Bg26) to observe and think whether his previous drawing was wrong. In this stage of inquiry, the pivotal contribution Ge22 played a crucial role in leading the process of revising the group's working theories seamlessly. On the contrary, the latent pivotal contribution T29 of the teacher's instruction of asking the students to stop working on their own group work was not followed by the group and hence did not influence the group's progressive process.

Stage 5: Build new working theories of the bulb circuit and share the co-constructed artifacts on the group board through experimentation and collaboration (Be31–Bg35): Enlightened by Agnes, Bruno (Be31) began to explore new information further through experiment in order to externalize his understanding. Agnes (A33) deemed that Bruno was able to understand how to build the new working theories of the bulb circuit and asked Bruno to continue Agnes' (Ag32) uncompleted drawing. Bruno (Bg34) completed the drawing of the bulb circuit with one bulb and two batteries. Agnes and Bruno exhibited mutual understanding at this stage, and the manifested pivotal contribution Be31 helped the group advance their working theories posted on the group board seamlessly.

At each stage of the group progressive inquiry, we also examined the uptake paths to find out the types of uptake (see Table 15.2).

Table 15.3 shows that Stage 1 had the least types of uptake, and Stages 3, 4, and 5 had the most types of uptake. This indicates that in the course of the progressive inquiry, more varieties of the types of uptake might be involved. In addition, Stages 3, 4, and 5 accounted for more percentage of uptake (35.42, 20.83, and 20.83 %, respectively) than Stages 1 and 2 (12.50 and 10.42 %). This indicates that students were more engaged in the progressive inquiry over time.

Uptake Paths for the Progressive Inquiry at a Theoretical Level

In this section, we provide evidence of how the uptake paths supported group progressive inquiry by focusing on visualizing of the evolving process of the shared artifacts using the trialogical approach in GS. The dataset was chosen from Stages 4 and 5 (from Ge22 to Gg35) shown in Fig. 15.2.

The essence of trialogical approach is to examine student inquiry learning through the collaborative development of mediating shared knowledge artifacts or objects instead of focusing on monologues in mind or dialogues between minds (Hakkarainen & Paavola, 2009). The analysis of the two stages was to elaborate how the students progressively revised concrete shared knowledge artifacts to construct knowledge. For the convenience of elaborating the approach, we put the development of shared knowledge artifacts in GS in the upper row and the other modalities (the verbal interactions and experimental practices in the two progressive inquiry stages) in the lower row as shown in Fig. 15.3. In the figure, the arrows indicate the uptakes of information from previous contributions.

Table 15.3 Types of uptake at each stage of group progressive inquiry

Stage (contributions)	Stage 1 (O1–S4)	Stage 2 (Je5–S10)	Stage 3 (Gg11–Bg21)	Stage 4 (Ge22–T29)	Stage 5 (Be31–Gg35)
Types of uptake (number)	1	3	9	7	7
Total number of uptakes (%)	6 (12.50)	5 (10.42)	17 (35.42)	10 (20.83)	10 (20.83)

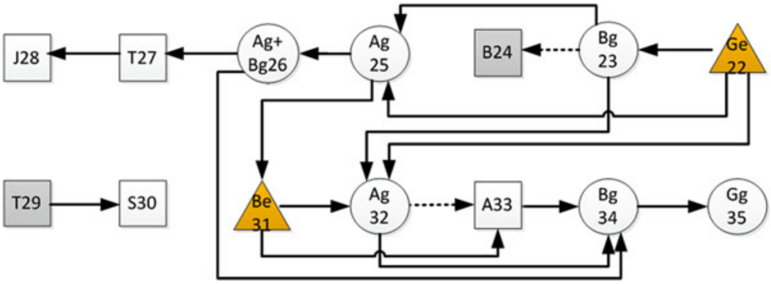

Fig. 15.2 Evolving process of shared artifacts

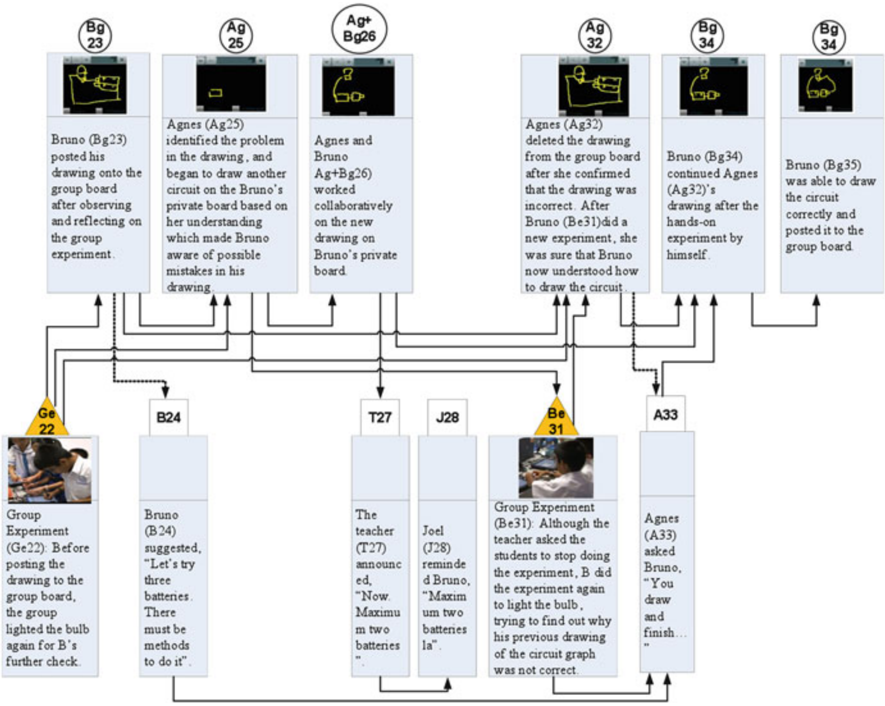

Fig. 15.3 Co-construction of shared knowledge artifacts in GS in the progressive inquiry

Figure 15.3 shows that the progress of co-construction of the shared knowledge artifacts (Bg23, Ag25, Ag + Bg26, Ag32, Bg34, and Bg35) involved the multimodal interactions and mediations between experimental practices, speech, and online communication in GS. First, Bruno (Bg23) posted the artifact of his conceptualized working theories of lighting up the bulbs onto the group board after further checking the group experimental practice (Ge22). The group shared artifact helped Agnes to visualize the working theory, which encouraged her to work on a new artifact to externalize her understanding. The artifact (Ag25) created by Agnes could be traced back to the group experimental practice (Ge22). The shared experimental practice shown visibly to Agnes mediated her to re-work on the artifact (Ag25) in GS, which, in turn, mediated Bruno to reflect on the artifact that Agnes was working on and work together with Agnes on collaboratively constructing the artifact (Ag + Bg26). While working on the shared artifact, Bruno did the experiment again (Be31), which mediated him to work out the knowledge artifact (Bg34) and post it to the group board as group shared knowledge artifact (Gg35). We have to point out that the process of the evolvement of the student knowledge artifacts was contributed by the interactions and mediations between different artifacts, experimental practices, and online F2F communications. The pivotal contributions from the group (Ge22) and Bruno (Be31) played significant roles in the evolvement of artifact construction.

Discussion

In this chapter, using an interaction analysis method we identified pivotal contributions in different transitional stages and five stages for progressive inquiry in the uptake paths. The method provides a lens to help us understand the group progressive inquiry into how to connect a closed electric circuit that can light up a bulb or bulbs and how to conceptualize the mechanism of the closed electrical circuit. In addition, adopting the trialogical approach to analyze the development of shared knowledge artifacts created in GS, we are able to visualize how the group of students constructed knowledge progressively through multiple mediations and interactions between different modalities.

Regarding pivotal contribution/moments, we extracted and analyzed a short dataset and identified seven pivotal contributions (four manifested and three latent) using an interaction analysis method. A pivotal contribution is defined as a "contribution that shifts the direction of subsequent events, whether seamlessly or abruptly, through uptake between the pivotal and subsequent contributions." Direction refers to a transition from one segment of an event to another indicated by a shift in an activity occurring at a segment boundary. Further, we classified the pivotal contributions into two types: manifested and latent pivotal contributions. It was noted that only the four manifested pivotal contributions were taken up and shape the course of the group inquiry. The three latent pivotal contributions were unrealized potentials. The pivotal contributions demonstrated characteristics of group processes of seamless transition to a new stage/direction of inquiry or an abrupt transition to a new line of inquiry. The pivotal contributions were identified not only by looking into the uptake structure but also by referring to the transcripts. However, the uptake structure helped us locate some possible pivotal moments and transitional boundaries in the uptake diagram for students' progressive inquiry.

For the purpose of multivocality, the other papers (e.g., Medina, this volume, Chap. 16; Lund & Bécu-Robinault, this volume, Chap. 17; and Jeong, this volume, Chap. 18) also analyzed the same dataset with different time stamps in this volume. Due to the different referential frames and analytical methods/approaches adopted, each paper interpreted the data and presented the research results in terms of pivotal contributions/moments and group meaning-making process differently. As we have different understanding of pivotal contributions and adopted different analysis approaches, the focus of the data interpretation was different, which influenced the results of the analysis. In our analysis, an uptake analysis method was adopted to identify pivotal contributions and transitional stages for progressive inquiry at a surface level first, and then we focused intensively on the development of shared knowledge artifacts created in GS using the trialogical approach to analyze it at a theoretical level. The progressive development of shared knowledge artifacts is indispensable to the interaction and mediation (coordination in Medina's case) of the multimodalities (media in Medina's case). The uptake analysis presented in our paper shows that it was not only the GS technology that mediated learning, but also the student, teacher, GS artifacts, and experimental practice all became mediating means to make the progressive inquiry happen and at different points in time. In addition, adopting the trialogical approach to examining the group's evolvement of shared knowledge artifacts helped us understand the process of group cognition as students developed and explored working theories of electrical circuit visible or "materialized" (Hakkarainen & Paavola, 2009) in GS progressively.

Medina's analysis (Chap. 16) adopts a sequential analysis approach in which pivotal moments are related to pivotal sequence of interactions, in which "the group members develop an innovation for lighting two bulbs with one circuit." In his analysis, the focus is on pivotal moments where "uptakes from multiple media [verbal, nonverbal, textual, and visual-spatial] converge to the identification of a discrepancy and the need to correlate them." It seems that the verbal media that originated from the teacher is considered "a third party" (cited from Medina's e-mail dated on 24 March 2012) to the convergence. The analysis approach is to perform "iterative readings to build a tractable structure for understanding how persistent media is appropriated in contexts of interaction" and to then construct an innovation as a joint activity. Although the dataset in our analysis correlates with Medina's dataset of experiments 2 and 3, our interpretation of the teacher's intervention (T12) to ask the group to draw their electrical circuit of lighting one bulb using two batteries in GS was considered pivotal to shape the students' inquiry to a higher level for conceptualization, while Medina's interpretation is that the teacher's intervention was abrupt and "splintered, temporarily, a coherent element of the building of intersubjectivity" (cited from Medina's e-mail dated on 24 March 2012).

In Lund and Bécu-Robinault's analysis (Chap. 17), a given mode/medium couplet is defined as "a potential pivotal moment that may be important for conceptual change." In their analysis, pivotal moments resulted from different types of talk—“both for reformulation across semiotic systems, and for profiting from reformulation in order to extend or change theories and ways of linking objects and events to move towards talk and actions compatible with canonical physics theories.” Lund and Bécu-Robinault’s interpretation of group understanding focused on the potential of pivotal moments—a reformulation across modes/media. A reformulation is pivotal when it contributes to the students’ conceptual change of physics theories. The authors postulate that “particular types of talk—in their interactional context, coupled with the use of external representations and gestures in their immediate interactional vicinity—will play a role in instigating such theory change.” This appears to be at a higher level of analysis to identity transformation to demonstrate understanding. The identified pivotal moment in the dataset that overlapped with ours is the third instance of reformulation provided in Lund and Bécu-Robinault’s writing-up, which started by Serena, “who, inspired by the collective experiment, begins a drawing in Bruno’s GS space, which he then finishes.” Their interpretation was that Serena performed “types of reformulation, one that is a hetero reformulation of Bruno’s incorrect drawing, but also one that is reformulating the (manipulating, object-events) collective experiment to the (drawing, GS) couplet.” The conceptual change is revealed through Bruno correcting his drawing and thus “potentially experienced conceptual change.”

Jeong’s analysis (Chap. 18) focuses on one modality—artifacts—to investigate group understanding, which was revealed progressively via the construction of physical (experiment) and digital (GS) artifacts. The analysis “examined [students’] circuit understandings reflected in either GS or physical artifacts only.” The dataset in our analysis corresponds to the dataset in Jeong’s analysis of group co-construction of Circuit B (both B1 and B2). Circuit B1 refers to the bulb connected to the batteries with two pieces of wire, while Circuit B2 refers to the bulb connected to the batteries directly on the top. Based on the analysis of group co-constructed physical (experiment) and digital (GS) artifacts separately, Jeong posits that each understanding of circuit was a close extension of the preceding circuit.

We also note similarities in our analyses. For example, in Medina’s analysis of Experiment 4 of lighting a bulb using two batteries, it states, “when Serena notes a discrepancy between the manipulated circuit and the diagram, and the group adjusts to bring the two into alignment. This is pivotal as there are uptakes from multiple media that converge to the identification of a discrepancy and the need to correlate them.” Although we did not distinguish “media” with “modalities” in our writing, we agree that the convergence of discrepancy between the diagram (in our case the GS artifacts) and the manipulated circuit (in our case, experimental practice) was the product of interactions and mediations between different multiple modalities (media in Medina’s case).

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Appendix

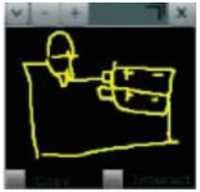
Transcripts of data on electricity for the uptake analysis (from 00:12:15 to 00:16:16)

Time	Label	Name	Observable action, discourse (including graphs), or content: Face-to-face conversations and gestures	GS artifacts	Screenshots of student trial–error experiments
12:15	O1	Others	*(To S)* You can try to use two batteries (*using a gesture with his fingers*).		
12:18	J2	Joel	*(J overheard what O said and understood his gestures.)* Bright idea.		
12:19	B3	Bruno	*(To the group members)* Yeah.		
12:21	S4	Serena	*(To the group members)* Let's try two batteries. We connect all of them? *(Using her fingers to make a gesture of two. All of them got excited.)*		
12:38	Je5	Joel starting the experiment	*(To B)* Wait! Wait! I know! Quickly, connect the wire! B, hold here! Hold it hold it. Hold it properly. Ok, hold it.		
12:47	Ge6	Group experiment	*(B connected the wires with the two batteries to light the bulb, but the bulb was not lighted.)*		
12:49	S7	Serena	*(To B)* Hey! Wrong side *(The bulb was not lighted.)*		

12:52	Ge8	Group experiment	*(The group tried again, and this time the bulb was lighted by B's final touch.)*	
12:53	J9	Joel	Hey, very bright.	
12:54	S10	Serena	*(To the group members)* How about we try two batteries, two bulbs? Two bulbs?	
13:05	Gg11	Group in GS	*(The group board is empty. T looked at the group board.)*	
13:06	T12	Teacher	*(To the group)* No draft, no draft [*on the group board*]. Then people will look at a blank board.	
13:07	B13	Bruno	*(To T)* I'll draw, I'll draw.	
13:10	T14	Teacher	*(To the group)* Where are the two batteries?	
13:13	J15	Joel	*(To T)* We can do with two batteries.	
13:15	T16	Teacher	*(To the group)* One draws, one member draws … *(Stopped for a few seconds)* One member draws. The other three do the fix and circuit.	
13:25	Bg17	Bruno in GS	*(To T)* I'm drawing, I'm drawing.	

(continued)

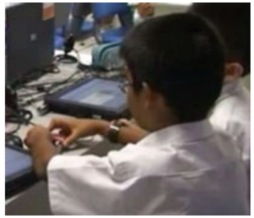
Appendix (continued)

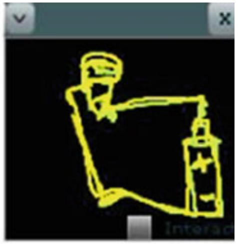
13:27	Je18	Joel starting the experiment	*(To S)* Hey, *S*. Hold this. Hold this. You hold here. Hold here. Hold here. *(S and J begin to connect the wires with the two batteries to light the bulb again to make B understand how to draw the circuit.)*		
13:38	Bg19	Bruno in GS	*(B is drawing and did not look up)* Hey, don't knock my hand.		
13:47	T20	Teacher	*(To the class)* Try various ways. Use two wires. *(Stopped for a few seconds.)* Now children, 5E *(this class number)* gave me more varieties you know? 5E, I want team work.		
14:16	Bg21	Bruno in GS	*(B finished the drawing of the graph of circuit with two wires and two batteries to light the bulb they experimented just now on his private board.)*		
14:28	Ge22	Group experiment	*(Before posting the drawing to the group board, S and A lighted the bulb again for B's further check.)*		

14:29	Bg23	Bruno in GS	*(B dragged the drawing of the circuit with two wires and two batteries on the left together with his previous drawing of the circuit with two wires and one battery to light the bulb on the right from the private board to the group board.)*	 B posted his drawing (*on the left*) together with his previous drawing (*on the right*) onto the group board.
14:30	B24	Bruno	*(To group members)* Let's try three batteries. There must be methods to do it.	
15:03	Ag25	Agnes in GS	*(After observing the hands-on activity about using two batteries to light one bulb, A began to draw on B's private board according to her understanding.)*	
15:10	Ag+Bg26	Bruno in GS	*(While A is drawing, B is looking at and pointing to the drawing. He realized that his previous circuit graph was wrong. Ag had no time to finish the drawing; she asked Bruno to finish the rest.)*	
15:11	T27	Teacher	*(To class)* Now. Maximum two batteries.	
15:13	J28	Joel	*(To B)* Maximum two batteries la.	

(continued)

Appendix (continued)

15:19	T29	Teacher	*(To class)* All right, children, I think it's enough now. Stop what you're doing. Now, I want you to visit other people's board and see whether there are new ideas. If you got different ideas, you can clone your friends' board and paste it into your own group board. And circle it to show me that you borrow the ideas. Now you can visit your neighbor's board.	
15:50	S30	Serena	*(To group members)* Teacher said we cannot do la.	
15:52	Be31	Bruno's experiment	*(Although the teacher asked the students to stop doing the experiment, B did the experiment again to light the bulb, trying to find out why his previous drawing of the circuit graph was not correct.)*	
15:53	Ag32	Agnes in GS	*(To B, pointing to the drawing of the circuit with two batteries to light the bulb on the group board that B drew previously.)* It's not like that. Not like that. Cancel this one la.	 A deleted the drawing from the group board
16:03	A33	Agnes	*(To B, pointing to the drawing)* B, you draw and finish. Draw and finish *(A is observing B's drawing).*	

16:10	Bg34	Bruno in GS	*(B is drawing.)*	 B continued A's drawing (16:03)
16:16	Gg35	Bruno in GS	*(B removed his previously published drawing and posted the revised drawing of the circuit with two batteries to light the bulb as the group work to the group board.)*	 

O = Others, A = Agnes, B = Bruno, J = Joel, S = Serena, T = Teacher, G = Group
Gg = Group working in GS (creating, editing, or moving a GS post)
Ag = Agnes working in GS, Bg = Bruno working in GS, Ag + Bg = Agnes and Bruno both working in GS
Ge = Group experimental practice, Be = Bruno's experimental practice, Je = Joel's experimental practice

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