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ABSTRACT

Collaboration is an essential part of problem-based learning (PBL), but detailed understanding about how interaction between PBL participants leads to co-construction of knowledge is still quite scarce. This study attempted to address this issue by analyzing the phases of interaction between three teachers in a professional education setting solving a real-world problem over the course of seven weeks. Other data such as documents and artifacts created by the participants were also analyzed in relation to the interaction, allowing for triangulation of data as well as richer description of the advances of the interaction. What emerged were six phases that conceptually depict the interactional interplay between the actors in the process of social construction of knowledge in this PBL setting. These phases provide a lens in which to view and understand the phases of interactional interplay between PBL actors. This outcome can eventually contribute to more detailed guidance on how certain types of discourse moves can advance these phases of interaction.

Keywords: teacher education, problem-based learning, collaborative learning, pedagogy, student engagement

Introduction

The process and outcome of problem-based learning (PBL) can be uneven and unpredictable (Mamede et al., 2006; Colliver, 2000; Azer, 2001; Norman & Schmidt, 2000). Hmelo-Silver's (2004) problem-based learning cycle provides a broad overview of the pathway a PBL process should go through, but more studies are needed to better understand the interactional interplay between the actors in a PBL setting (Imafuku & Bridges, 2016; Imafuku et al., 2014). It is this interactional interplay that this study sought to describe. Part of this interactional progression can be broadly seen in Stahl's (2000) model of collaborative knowledge building. However, a more specific and detailed conceptual description of the interaction phases and cognitive activities that represent the flow of social construction of knowledge in PBL settings can provide a lens in which to view and better understand the phases of interactional interplay between PBL participants. This paper reports the findings of a study that attempts to fill this gap.

Literature review and conceptual framing

The conceptual links of problem-based learning to constructivism have been widely discussed (Hendry et al., 1999; Schmidt & Moust, 2000; Savery & Duffy, 2001; Savery, 2006; Dolmans et al., 2005; Pelech, 2008). Hendry et al. (1999), for example, gave a detailed analysis of various elements in the practice of PBL linked to constructivism. Savery and Duffy (2001) pointed out that PBL is consistent with the underpinnings of constructivism: (1) students are actively involved in constructing their own understanding and meaning of reality through solving complex, real-life problems; (2) the problem presented in a PBL context is often complex and ill-structured (i.e., it often has no single right answer); therefore the parameters of the problem are less defined, which potentially creates cognitive puzzlement; and, (3) group interactions provide a rich social environment and mechanism for students' understanding to be tested and challenged.

What is less evident is how the social construction of knowledge in PBL actually occurs (Hmelo-Silver & Barrows, 2008). Various PBL researchers have argued that more research is needed to explicate the theoretical concepts underlying PBL and how a PBL collaborative process works (Dolmans et al., 2005; Mamede et al., 2006; Hmelo-Silver, 2009). Hmelo-Silver and Barrows (2008), for example, demonstrated that different kinds of questions and statements contributed by the facilitator and the students helped advance the process of collaborative knowledge construction. In their study, as the PBL group progressed in their discourse of the problem, the causal explanations became more coherent. Over time, the group formed a deeper and richer understanding about the problem situation. The study shed some light on the kind of discourse that could advance the process of collaborative knowledge construction in a PBL setting. However, Barrett (2010) pointed out that although the students' discourse during the PBL process is pivotal to the outcomes of the PBL process, few studies have provided more detailed analyses to further enhance the understanding of how the collaborative interactions lead to effective PBL.

In a number of past studies, researchers have studied emerging indicators in the process of collaborative construction of knowledge in PBL groups. For instance, Norman and Schmidt (1992), in their review of literature, concluded that group discussions in PBL promoted the activation of prior knowledge and elaboration. De Grave et al. (1996) found that PBL students' cognitive conflicts during discussions about the problem led to a more nuanced restructuring of knowledge or a conceptual change in the understanding of the problem. Another study (Visschers-Pleijers et al., 2004) reported on the presence of questioning, reasoning, elaboration and attempts to solve cognitive conflicts as essential parts of co-construction of knowledge. While these studies highlighted the different kinds of cognitive interactions that occur in PBL discourses, they did not describe the developmental stages or phases of how interactional aspects such as questioning, conflict and elaboration advanced the co-construction of knowledge. Another study detected the presence of elaboration and co-construction in three separate aspects of the group interactions, namely questioning, reasoning and conflict (Visschers-Pleijers et al., 2004), but it did not describe the developmental phases in how these interactional aspects worked together to advance the social construction of knowledge. Another example is a study that focused on how providing explanations and listening could affect long-term memory, but it did not quite explicate the details of what happens in the advancement of the explanation and listening process (van Blankenstein et al., 2011).

This study aims to take the previously discussed studies a little further. Specifically, this study seeks to describe the advancing phases of social interactions that lead to the social construction of knowledge in a PBL setting. The focus is on examining the process of social construction of knowledge, guided initially by Stahl's (2000) model of collaborative knowledge building and Gunawardena et al.'s (1997) Interaction Analysis Model (IAM). The main focus of these models–and as such the focus of this study–include the sharing of information, exploration of hypothesis, cognitive dissonance, social negotiation, testing of new understanding and knowledge, and the emergence of social artifacts as well as their respective cognitive activities that manifest in the PBL interactions. The roles of these models are discussed with more detail in the following sections.

Background of research context and conceptual linkages

A master's level instructional design and technology course was the context where this study was carried out. The course has two key elements that contributed to the framing of this study, which also made it suitable for this project. First, the course has the characteristics of a PBL environment as described by Hmelo-Silver (2004). Second, the course objective is to help students enrolled in this class (who are also educators i.e. a teacher, a principal and an instructional designer) to develop technological, pedagogical, content knowledge (TPACK; Mishra & Koehler, 2006). The following discussion unpacks how these elements are key parts in the framing of this study.

According to Hmelo-Silver (2004), PBL is an instructional method in which students learn through facilitated problem solving, collaboration, self-directed learning and reflection. In PBL, student learning revolves around a complex problem that does not have a single correct answer. As students handle the problem throughout this course, they learn to construct new understandings where their knowledge of content, pedagogy, and technology (TPACK) intersects and intermingles. Thus, they develop new understandings to guide teaching with technology decisions and practices that work best for a given content and context (Koehler & Mishra, 2005; Tee & Lee, 2011). In this course, the problem to trigger the PBL process emerges from the students' context, under the close facilitation of the instructor. Based on Jonassen and Hung's (2008) typology of PBL problems, the problem that emerged here can be characterized as having a blend of "diagnosis-solution" and "design problem" features. The students had to diagnose the root problem of the situation they identified (which is the focus of this paper) and were required to design an instructional plan to solve the problem. This simulated problem matches the real-world experiences students will

face in daily practice. Equally important, this problem has the kind of nuance and complexity needed to be a catalyst in cultivating TPACK.

To cultivate TPACK, students must have a good understanding of the individual components of TPACK and how these components interact and produce transactional relationships in a given educational context (Koehler & Mishra, 2005; Tee & Lee, 2011). Fundamentally, the three components are technological, pedagogical, and content knowledge, represented by three intersecting circles (Mishra & Koehler, 2006). Content knowledge (C) has to do with the subject matter or domain area that is to be learned. Technological knowledge (T) broadly encompasses a spectrum of information and communication technologies, from books and blackboard to internet-enabled mobile devices and digital games. Pedagogical knowledge (P) has to do with the process and practice or methods of teaching and learning, including the purposes, values, techniques or methods used to teach, and the strategies for evaluating student learning. When these knowledge bases intersect, the emerging new understandings can help in making better decisions for teaching and learning with technology. For instance, pedagogical content knowledge (PCK)—initially conceived by Shulman (1986, 1987)—combines knowledge of pedagogy in specific content areas. This concept is observable in teachers who are able to use role-playing games (pedagogy) effectively to help students understand the challenges faced by individuals as they explore new frontiers in the 15th century (content). However, PCK is not merely about utilizing certain strategies for certain content. It also relates to how well that particular strategy is useful to facilitate learning.

Ultimately, a teacher that has TPACK can demonstrate a nuanced competency and understanding of how a combination of certain technologies and pedagogical techniques can make learning a particular content area more meaningful. However, developing an in-service teacher's TPACK cannot only occur through direct instruction (Koehler & Mishra, 2005). One way to expand these skills is to introduce an in-service teacher's problem of practice into a PBL classroom, as done in the selected setting for this study. This scenario creates opportunities for the in-service teachers to work on an authentic problem with which they can identify, analyze and solve. Then, the teachers will eventually select and use the most appropriate combination of pedagogy and technology to address the problem (Barab & Duffy, 2000; Koehler & Mishra, 2005; Tee & Lee, 2011). In this PBL process, they should not only learn about technology but also "how to learn" about technology and "how to think" about technology in a manner that is most appropriate for the situation in which they find themselves. This approach particularly helps engage students towards intended learning outcomes (Koehler & Mishra, 2005; Tee & Lee, 2011), which is done in collaborative settings.

Not all collaborative settings are created the same, however. Some scenarios are more open-ended and unpredictable, and others are more structured and more tightly facilitated. To carry out this study, the researcher needed a framing that provided enough guidance to identify a research site that would most likely see the different aspects–questioning, reasoning and conflict–and phases of interactions in action. Stahl's (2000) model of collaborative knowledge played this role.

In summary, this study seeks to describe and better understand the aspects and phases of social interactions that lead to the social construction of knowledge in a PBL setting. It is guided by the following research question: What and how do the different aspects (questioning, reasoning and conflict) and phases of interactions contribute to the social construction of knowledge in a PBL setting? The focus is on examining the process of social construction of knowledge, to explicate what actually happens in the interactions as students attempt to construct knowledge in a PBL setting.

Methods

Research Design

The goal of the instructional technology course was to help students who are in-service educators develop a more nuanced understanding of TPACK. The development of TPACK cannot just occur through direct instruction (Koehler & Mishra, 2005; Tee & Lee, 2011). An additional method that has shown potential is through PBL. This course had the essential elements suitable for this study–it used a PBL approach similar to what is described in Hmelo-Silver's (2004) six-step problem-based learning cycle. This, together with Stahl's (2000) model of collaborative knowledge building processes, were used as initial guides to identify an information-rich PBL site where the process of social construction of knowledge was likely to happen. This structure led to the selection of this instructional technology course offered in a master's program at a public university in Malaysia.

As the program was in the midst of being discontinued, the course had only three students–Jasmin, Rina and Farah (all pseudonyms). Jasmin was a high school English teacher. Rina was a full-time student whose previous job experience included designing science educational courseware. Farah was the principal of an elementary school, which was particularly well equipped with information and communications technology (ICT) facilities. Both Jasmin and Farah were seasoned teachers with each having at least 10 years

of experience. The course instructor (I) served as the PBL facilitator. All participants gave their informed consent. The 14-session course (3 hours per session, per week) was divided into two major parts. Each part–lasting over seven sessions–focused on a PBL case. Sessions 1 to 3 were facilitated to give the participants opportunities to define and conceptualize the problems they had decided to work on as a PBL group–much like "diagnosis-solution" problems described by Jonassen and Hung (2008). They were asked to scrutinize the challenges they faced at work through the TPACK lens. Their problem of focus had to be directly related to teaching and learning (as opposed to broad policy issues or purely technical problems). The problem also had to be complex, rather than too simplistic. (For example, "The LCD projector in my school is unreliable," is too simplistic a problem.)

Farah, for instance, was quick to provide details about how the teachers in her technology-rich school were reluctant to use technology to help improve teaching and learning. At this stage, the participants worked through a number of tentative hypotheses (i.e., possible root causes of the problem), and in the process they became more aware of the knowledge gaps that existed as barriers to addressing the problem. These gaps included a list of learning issues the participants had collaboratively formulated for further research as well as evidence or data that had to be collected to validate their arguments or reasonings. These early sessions were the main focus of this analysis.

Sessions 4 to 5 were created for the group to consider different solutions to the problem, and propose and select a solution. Session 6 allowed the group to implement the selected solution in a pilot or full-blown situation. Sessions 4 to 6 had features similar to design problems described by Jonassen and Hung (2008), and as such were more tightly facilitated. Session 7 was designed for the participants to present and discuss more formally the process and outcome of the entire learning cycle.

Throughout the course, the participants worked iteratively through collaborations and self-directed activities. This paper reports on the second problem case. The three participants worked on a real-life problem that existed in Farah's school. It was a school rich with technology but few teachers were integrating it into the teaching and learning activities. As discussed earlier, this created opportunities for the in-service educators to work on an authentic problem with which they could identify and then collaboratively analyze and solve. Eventually, they were able to select and use the most appropriate combination of pedagogy and technology to address the problem (Barab & Duffy, 2000; Koehler & Mishra, 2005; Tee & Lee, 2011). Through this process, opportunities to develop TPACK were created. In the context of this paper, the focus of analysis will be on the initial stages of PBL.

Data collection and trustworthiness

Three key sources of data were collected for this study: observations, documents and artifacts created by the participants. The primary data–the interaction between the participants–came from observations, field notes, and video and audio recordings. After obtaining informed consent from each participant, the first author observed each session and took brief field notes. He also relied on video recordings and audio recordings to capture the interactions and actions that took place. Documents and artifacts were collected to capture the context in which the interactions were taking place and also to allow for thick description. These materials included participants' journals, online discussion threads, and the electronic wiki book (eBook) that was collaboratively written by the participants. The multiplicity of data also allowed for triangulation.

Member checks were conducted through emails to the participants. Each participant received a copy of the draft case study report and was asked to review it for accuracy. An audit trail was also created to enhance reliability. The researcher was also on-site at all of the PBL sessions to ensure adequate engagement. The raw data and ongoing analysis by the first author were also reviewed by the second author, as part of the peer debriefing process.

Data analysis

Because the aim of this study is to describe and better understand the phases of social interactions that lead to the social construction of knowledge in a PBL setting, interaction analysis is ideal. Interaction analysis is a method of investigating "the interaction of human beings with each other and with objects in their environment" (Jordan & Henderson, 1995, p.39). This definition highlights methodological congruence with the PBL process, which also requires human beings to interact with each other and with the problem they are trying to solve. Similar congruence also emerges in the assumptions of interaction analysis. Interaction analysis also sees learning as an ongoing social process, and that the evidence of learning must be found in understanding the ways in which people collaboratively do learning and recognizing that learning has taken place (Jordan & Henderson, 1995; Garfinkel, 1967). In this regard, the interaction analysis method also allows for the kind of flexibility needed to understand the data emerging from exchanges between learners in relation to the problem they are trying to solve.

The coding process began as the researcher made notes, comments and observations about the data discovered to be relevant to the research question, according to the theoretical framing of the study (Merriam, 2009). These notations were then associated with the codes based on the parameters and concepts from two frameworks that are discussed below in further detail. A category is created when these notes and codes with similar conceptual characteristics are grouped together. In this study, the analyses were discussed and reviewed with the second researcher as part of the peer debriefing process. Consensus had to be reached before the coding was finalized.

Stahl's (2000) model of collaborative knowledge building was used to guide the initial analysis process. The model provided a framework to focus on units of data that can be relevant or meaningful to the analysis of the PBL interaction phases. However, as the data emerged and salient events pertinent to the research framing occurred, some limitations were found in Stahl's model–the phases were too broad. The model lacked the specific details necessary for the investigation of the process of social construction of knowledge. For instance, "shared understanding"–listed in the model as a phase of the collaborative knowledge building process–lacked the details of a processual framing that explained the interactive development of "shared understanding". As a whole, the broad description of Stahl's model was important in helping to identify the research site. However, another lens was needed for better guidance into analyzing how interactions lead to social construction of knowledge. In other words, the emerging data indicated that a new framework was necessary. Initially, a completely emergent approach was proposed to explicate Stahl's model further. As the analysis progressed, Gunawardena et al.'s (1997) IAM proved more useful with a semi-emergent analysis approach. The IAM outlines the five major phases of interaction the participants experienced as they engaged in a computer-mediated discourse on the subject of distance education. Each of the phases is further broken down into specific, identifiable cognitive operations of the participants' contributions to the discourse. Table 1 provides a summary of the different phases, with asterisks highlighting the changes or additions made to the original IAM model based on the emergent data from this study.

PHASE I: SHARING/COMPARING OF INFORMATION		
*A.	Sharing or asking and answering questions to share an observation or opinion from one or more members	[PhI/A]
B.	A statement of agreement from one or more members	[PhI/B]
C.	Corroborating examples provided by one or more members	[PhI/C]
D.	Asking and answering questions to clarify the details of statements or examples	[PhI/D]
**PHASE II: EXPLORATION OF HYPOTHESIS OR OPINIONS		
A.	Providing data/information that relates to a hypothesis or opinion	[PhII/A]
B.	A statement of hypothesis from one or more members, asking and answering questions to clarify the details of hypothesis	[PhII/B]
C.	Asking questions or making statements to prompt members to respond to a set of data or to validate a hypothesis or opinion	[PhII/C]
D.	Building and providing a statement of justification to validate a hypothesis or opinion	[PhII/D]
E.	Identification of specific evidence/data to be collected to validate a hypothesis or opinion	[PhII/E]

Table 1. The modified Interaction Analysis Model (mIAM)

PHASE III: DISCOVERY AND EXPLORATION OF DISSONANCE OR INCONSISTENCY AMONG IDEAS, CONCEPTS OR STATEMENTS		
***A.	Expressions of doubt or puzzlement or disagreement by one or more members	[PhIII/A]
B.	Identifying and stating areas of disagreement or inconsistency	[PhIII/B]
C.	Asking and answering questions to clarify the source and extent of disagreement or inconsistency	[PhIII/C]
D.	Restating the member's position, and possibly advancing arguments or considerations in its support by references to the member's experience, or formal data collected	[PhIII/D]
PHASE IV: NEGOTIATION OF MEANING/CO-CONSTRUCTION OF KNOWLEDGE		
***A.	Asking and answering questions, or sharing an idea to negotiate for a new and deeper understanding underlying an issue	[PhIV/A]
B.	Proposal and negotiation of new statements embodying compromise, co-construction	[PhIV/B]
PHASE V: TESTING AND MODIFICATION OF PROPOSED SYNTHESIS OR CO-CONSTRUCTION		
A.	Testing of new statement against personal experience	[PhV/A]
B.	Testing of new statement against formal data collected	[PhV/B]
PHASE VI: AGREEMENT STATEMENT(S)/APPLICATIONS OF NEWLY CONSTRUCTED MEANING		
A.	Summarization of agreement(s)	[PhVI/A]
***B.	The proposal and design of cultural artifacts	[PhVI/B]
C.	Metacognitive statements by the participants illustrating their understanding/knowledge or ways of thinking (cognitive schema) have changed as a result of the social interaction	[PhVI/]

*Note: Re-phrasing the original IAM statements of operation to accommodate emergent findings.

**Note: An entire new phase was added to original IAM, based on emergent findings.

***Note: New statements of operation were added to original IAM, based on emergent findings.

Table 1 continued. The modified Interaction Analysis Model (mIAM)

Several key factors influenced the choice of IAM as an initial lens for analysing the PBL interaction. First, IAM was very similar to the key themes and dimensions that emerged in the data. IAM contains specific, identifiable phases and their corresponding cognitive operations to investigate the process of social construction of knowledge. For instance, in the IAM phase coded as 'negotiation of meaning/co-construction of knowledge' (Phase III), there were five specific, identifiable cognitive operations such as (1) 'negotiation or clarification of the meaning of terms'; (2) 'negotiation of the relative weight to be assigned to types of argument'; (3) 'identification of areas of agreement or overlap among conflicting concepts'; and so on. These detailed descriptions of the cognitive activities were extremely useful and responsive to the initial coding of the data. In addition, as affirmed by a number of other researchers, IAM offered a more holistic view of the flow of interaction and knowledge construction (Jeong, 2003; Lu & Jeng, 2006; Marra et al., 2004).

As highlighted by Gunawardena et al. (1997), these phases of interaction represented the movement of lower mental functions (which begins with the cognitive activities in Phase I) to higher mental functions as the process of social construction of knowledge advanced into deeper phases of the social processes. An important finding in this study was that the use of IAM to focus the initial inquiry did not deter the researcher from creating new categories to accommodate the emerging data. A new category or sub-category was created when emerging data in the PBL discourse showed recurring themes that were salient to answering the research questions (Merriam, 2009). An example of a new recurring theme in the emerging data was the generation of a tentative hypothesis by the PBL participants to address the problem scenario when the they were engaged in the 'hypothesis-generation' phase of the PBL cycle. The new cognitive activities that emerged from this phase of interaction were not represented in the IAM. Some examples of these new sub-categories of cognitive activities were (1) selecting and providing data or information that relates to an opinion or hypothesis that is being explored; (2) asking questions or making statements to prompt members to respond to a set of data or to validate an opinion or hypothesis; and so on. As a result, Phase II and its sub-categories (refer to Table 1: Phase II/A to Phase II/E) were created. They represented a category of social process in which the PBL participants shared and explored multiple perspectives or hypotheses in their efforts to conceptualize a shared understanding of the problem with which they were dealing.

As illustrated in the previous examples, new categories of cognitive activities, as represented by interaction phases, had to be introduced to account for emerging new patterns and themes. In turn, these new categories of cognitive activities were used as a guide for further analysis of data. Through this iterative process, the IAM was modified (i.e., mIAM; refer to Table 1) and represented the different phases of interaction that had occurred in the process of social construction of knowledge in the PBL discourse.

Findings and Interpretations

The findings will be described together with the corresponding interpretations in the form of an extended vignette that will explicate the phases of social construction of knowledge in a PBL setting. The description of salient events most relevant to the framing of this is study took place over three sessions and focused on the participants' analysis of the problem. Readers will see how the interactions move from Phase 1 to Phase VI as they construct knowledge together–advancing their TPACK in the process. (They read about TPACK as an introduction to the course.) An important note is that this pre-PBL reading was mainly intended to frame the domain or subject area for the students and to provide the basic language needed to communicate within this domain. As discussed earlier, reading or listening to a lecture about TPACK alone is not likely to help student learn how to develop TPACK.

Vignette: Early interaction mired in the initial phases of mIAM

After a lengthy discussion and clarification with the instructor, an agreement was reached to pursue a problem Farah had discussed earlier in class. As they engaged early in the problem definition phase of the PBL cycle, Farah began to describe her impression of the problem: "Teachers in my school, despite the wealth of technology they have, they shun away from using technology (to enhance student learning)…" [Video recording 6C, 35:58] (PhI/A).

She went on to explain that her school has more desktop and portable computers than students. Also, broadband connectivity as well as a series of technology software and hardware infrastructure was made available throughout the school. She was exasperated, however. The teachers were well-trained, but usage of the technology was poor. The technology-rich environment had not really improved student learning.

The focus of the initial interaction was on the clarification of information provided by Farah, based on her knowledge and experience as the principal of the school; therefore, it was not disputed. The social interaction remained at Phase I of the mIAM.

This pattern of interaction continued as they attempted to define the problem using evidence collected from existing institutional data. While this segment of the discourse

enriched their understanding of the problem, the participants continued to deal with emerging issues rather superficially. For instance, in one of the episodes, the participants (in a short one-minute conversation), offered six different reasons why the teachers were not using technology in their instruction:

The six reasons that they discussed were as follows: the teachers do not know how (Line 5), a problem with TPCK (Line 7), training (Line 9-11), implementation (Line 12), the school providing too much training to the teachers (Line 14), and no room for the teachers to sit and think (Line 15). As seen in the above exchanges, however, no one challenged the assumptions or the potential biases of these observations, and no justifications were given. In addition, the members

Line		Episode 8	mIAM Code	Time
1	[1]F:	I'm really frustrated, because the English class	PhII/A	6E, 07:33
2		I even subscribed for them, you know Enchanted		
3		Learning? I subscribed for them… also not put to		
4		good use.		
5	[1]J:	I think the whole problem now is they don't know…	Uncodable[2]	
6	F:	(Interrupt) No, that's why in my previous reflection,		
7		it's the TPCK (pointing to the whiteboard)!	PhII/B	
8	J:	Maybe they don't know. I think now the issue is…	Uncodable	
9	[1]R:	(Interrupt) But training should be…	Uncodable	
10	J:	(Interrupt) There is training.	PhII/A	
11	R:	Perhaps the training did not target…	Uncodable	
12	J:	There is no implementation… Maybe I give you	PhII/A	
13		everything, right? I train you (in) this…		
14	F:	(Interrupt) Sometimes I question myself, do I give	Uncodable	
15		too much…?		
16	J:	(Interrupt) No, I think, what, what, the issue here is	PhI/A	
17		you give them what they need but there is no room		
18		for them to sit, think and…		
19	F:	(Interrupt) Probably.	PhI/B	6E, 08:39

1 F, J and R are abbreviated forms for Farah, Jasmin and Rina respectively.

2 "Uncodable" refers to statements which carry unclear or ambiguous meaning in light of the study.

did not make efforts to listen to each other. Participants interrupted each other's conversations frequently (see Lines 6, 9, 10, 14, 16 and 19). Although disagreements began to surface (Lines 6, 16), these arguments were not taken up for further exploration and verification before they were interrupted by another new idea. Consequently, the members' ideas and arguments were not given the space to develop more fully. As a result, the conversation did not expand beyond Phase II of the mIAM.

Advancing into the Latter Phases of mIAM

As the instructor pushed the group to consider the root of the problem, a critical moment occurred which advanced the interaction beyond Phase II of mIAM. As they considered other causes, the participants began to explore different possibilities and different points of view. The instructor asked them to consider if they had evidence, and if they understood the magnitude of the issues they were raising (i.e., Were they assumed or substantiated issues? Were they isolated or widespread?).

Farah explained that the teachers in her school had the knowledge to use the technology, but they rarely used it. Jasmin began thinking out loud: "I think the issue now is they have the…" [Video recording 6E, 09:22]

Farah interjected excitedly, "… they have the T." ("T" refers to technological knowledge.)

"Yeah, they have the T," Jasmin said. [PhI/B]

Then Farah added, "They have the T, they have the P, they have the C. It is the [thing]…." ("P" refers to pedagogical knowledge and "C" refers to content knowledge) [PhI/A]

"…to merge, to bring them together," Jasmin continued Farah's thought processes [PhIV/A].

By this point, the conversation had moved from Phase 1/A to Phase IV/A of the mIAM. They began to ask more questions, which were answered by the rapid interaction between Farah and Jasmin. A new layer of socially constructed understanding began to unfold.

Farah went on to draw on the board what they were discussing. She drew two overlapping circles, labelling them P and C, and a separate circle labelled T. She explained further, "This is how it looks like. There is P. There is C. They are able to do this, pedagogy and content, they can do that [but]…." [PhIV/A]

Jasmin interjected again: "I think the problem is they do not know how to bring in T…" [PhIV/A]

"There is T, but T is not incorporated into this…," said Farah to complete Jasmin's sentence, gesturing toward the overlapping P and C circles on the board [PhIV/A]. Notice how they completed each other's sentences, moving from the initial Phase I-type statements to Phase IV-type co-constructions.

Then, the conversation continued into a statement of agreement [PhI/B], as Jasmin said, "Yes. But we need to verify this! Is this true?"

The, "Is this true," question takes the interaction back to PhII/C.

Farah justified her observation (PhII/D): "I'm saying that their T is almost 100%. Why is that? Because the administration of the school is totally digital. Technology in the administrative part…[that's] OK."

"We need to verify that," Jasmin and Rina said, seeking validation yet again for Farah's repeated claim (PhII/C). [Video recording 6E, 11:24]

By the end of this session, the teachers had proposed to analyze a number of existing institutional data as well as develop survey tools to verify their interpretation of the problem.

Deeper Probe into the Problem Continues to Lead to Latter Phases of mIAM

After the previous discussion, the participants collected data to verify their preliminary conclusions. As the group probed deeper into the root problem, Farah argued that the reason the teachers did not integrate their technological knowledge into their pedagogical and content knowledge was because they did not have the skills to do so (Episode 30, Line 1, 7-9). Her position shifted the framing of the problem–the participants had argued earlier that the root cause could possibly be due to other reasons, such as time constraints, lack of motivation, or that the teachers didn't see the benefits of using technology.

These exchanges exemplified a discourse whereby the participant's cognitive operations moved the process of social construction of knowledge from Phase III to advance to Phase PhIV/A (Line 7-9). This result is evident in how Farah pushed for a new line of discussion and a deeper way of looking at the problem ("Technology [knowledge is] high but [knowledge] to integrate [TPACK is] low").

The instructor affirmed this critical moment as he said, "Now, that's an interesting perspective. It does take a different skill to integrate. That's a very good observation!" [Video recording 8D, 16:45; PhIV/A]

However, the critical moment in which Farah initiated a new line of thinking was not taken up for further exploration. As the following exchanges show, the participants merely skirted around the issue. As the instructor tried to fade his scaffold (Line 1-2), the participants struggled to move the conversation forward–unsure how to validate the various possible root causes (Line 5-6, 10-12). They vacillated between 'do not know how' and 'do not want' to use technology. As a result, the conversation stayed within Phase II of mIAM:

Line		Episode 30	mIAM Code	Time
1	J:	Not that they don't know; they are not skilled!	PhIII/B	8D, 16:20
2	R:	Not skilled? (with doubtful tone and giggling)	PhIII/C	
3	J:	Not skilled, Farah? It's five! Five! Five! (referring	PhIII/D	
4		to the teachers scoring five-out-of-five for their		
5		technological knowledge based on an institutional		
6		survey)		
7	F:	No, they do not have the skills to integrate; they	PhIII/B	
8		do have the technological skills. Technology high		
9		but (the skills) to integrate (TPACK) low!	PhIV/A	8D, 16:33

Line		Episode 32	mIAM Code	Time
1	[1]I:	So, what do we do now? I'm trying very hard to	No code	8D, 18:16
2		fade here!		
3	F:	Probably see why…	Uncodable	
4	R:	Don't know how or don't want. If don't want, is it	PhII/B	
5		because no benefit or no time? Can we ask them	PhII/E	
6		*if they know [how to integrate]?*		
7	F:	Probably, when they said they used it once a	PhII/A	
8		month, it's like the ustaz (religious teacher),		
9		he is using CDs to demonstrate…		8D, 16:33
10	R:	If *they do not want to*, there are two possible	PhII/B	
11		reasons: no benefit or no time. One other reason is		
12		*that they do not know how, but is that valid?*	PhII/C	8D, 19:43

[1]I is abbreviation for Instructor

As can be seen from the above conversation, the participants were a little overwhelmed by the complexity of the problem as they struggled to articulate clearly the root cause. From the standpoint of knowledge construction, the participants' cognitive schema was not well organized. A degree of dissonance existed in their thinking about the root causes, which still has not been fully resolved. The instructor intervened and scaffolded the process of the interaction by playing devil's advocate: he tried to help them explore the possible root causes further, prompting the teachers to rethink how the root causes interacted with each other (Episode 38, Line 1-5, 12, 15).

Line		Episode 38	mIAM Code	Time
1	I:	But… even with the question of motivation,	PhIV/A	8D, 32:59
2		why are they not motivated? It can come back		
3		to the same reason: they are not motivated because		
4		they don't see the benefit. Or they are not		
5		motivated because they are lazy? Not really, right?		
6		Your teachers (referring to F) are fairly	PhIV/A	
7		hardworking, right?		
8	F:	Maybe just one (not so hardworking) …	PhIV/A	
9	I:	How many percent would you say are	PhIV/D	
10		hardworking teachers?		
11	F:	More than 70-80 percent.	PhIV/D	
12	I:	So most of them are hardworking, so motivation	PhIV/A	
13		is not a huge issue…?		
14	F:	But motivation for using technology is an issue…	PhIV/A	
15	I:	Right. So, the question is: why?	PhIV/A	
16	R:	They probably don't know how.	PhIV/A	8D, 33:58

This brought the discourse back to Phase IV of mIAM. This line of probing initiated by the instructor was caught on by the participants and using a similar approach, they began to co-construct a more cohesive understanding of the root problem and how it related to other possible root causes. This development is exemplified in the following discourse:

Line		Episode 39 & 40	mIAM Code	Time
1	J:	If they know how to integrate it well, then they will be	PhIV/A	8D, 35:16
2		able to see that the time issue would not be such a major		
3		issue because they would be able to see that although…		
4		it might take some time initially. But if they are able		
5		to see that by integrating this, in the long run, my students		
6		will benefit; the objectives will be achieved in a much		
7		easier way. I think all the other possible reasons can be		
8		put aside.		
9	I:	OK, you're making some progress here. So, one of the		
10		arguments is if they know how to integrate, time shouldn't		
11		be as big an issue because they know, in the long term, it		
12		evens out. What about the second one (referring to the		
13		reason 'no additional benefits')…		8D, 35:52
14	R:	No additional benefit; this has the same argument as	PhIV/A	8D, 36:31
15		time factor. If they already have the skills to do it, they		
16		can see the extra benefits the students will get.		
17	J:	If you use technology, this is based on my experience;	PhV/A	
18		there will be some changes because the students will be		
19		very excited and interested and of course the question will		
20		be: but does that ensure that the objectives are achieved?		
21		Based on my experience, it does. I might have listed three		
22		objectives and I might not be able to achieve all three but at		
23		least one will be achieved, which would be much difficult if		
24		that was a normal way of…		
25	R:	With no technology.	PhIV/B	
26	J:	Yes, with no technology.	PhIV/B	8D, 37:34

As evident in the above interaction, the social construction of knowledge progressed through Phase IV and Phase V of mIAM. From a list of random, seemingly unrelated hypotheses of potential root causes (for example, see discussion from Episode 8), the participants began to develop a clearer and a more coherent understanding of the problem. As their interactions advanced to Phases IV and V of the mIAM, their summarization and conceptualization of the problem became more particular and better justified. Jasmin, for instance, had initially argued very simplistically that time constraint was the main reason the teachers were not integrating their technological knowledge into their pedagogical content knowledge (8C, 07:36). As shown in the above interaction, Jasmin's thinking had undergone a substantive transformation. She was now able to reason why time constraint would not be a major issue when the teachers are able to integrate their technological knowledge with their pedagogical and content knowledge and that the learning objectives can be more effectively achieved (Line 1-8, 17-26). Jasmin would later conclude in her journal: "The case in our hands deals with teachers who do not have the skills to integrate technology into their lessons. This is the root cause."

Similarly, Rina demonstrated a growing nuanced understanding of TPACK when she expressed her conceptualization and summarization of the problem in her journal (Ph VI/B) (see Figure 1).

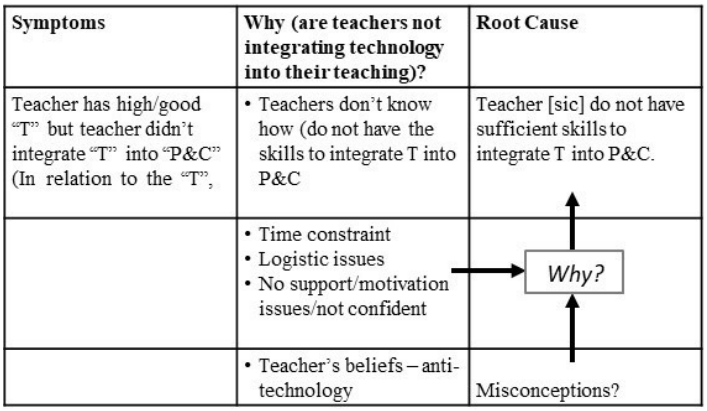

Figure 1. Conceptual artifact showing Rina's new way of thinking about the root causes (Reproduced from Rina's Journal reflection)

Rina's illustration (Figure 1) is primarily the result of the co-construction with her groupmates. The negotiation of meaning and co-construction (exploring and evaluating different possibilities, asking for and seeking verification, etc.) helped her to see that the initial list of causes (refer to the middle column of Figure 1) could be traced back to the teachers really not knowing how to integrate their technological knowledge into their existing pedagogical content knowledge. In Rina's own words, she wrote in her reflections: "Upon more discussion, we think that issues about time, logistic[s], motivation and others [are] actually under the umbrella of teacher[s] not having sufficient skills to integrate 'T' into 'P' and 'C'."

The design of this artifact was coded as Phase VI/B of mIAM. The conceptual transformation that occurred among the PBL participants was also seen in Farah when she reflected in her journal regarding the group's discussion. (Her statement reflected Phase VI/C of mIAM, indicating that her way of thinking about the problem had changed.)

> [This case]…challenged me to really look at the problem with different eyes and from many angles. I have to break away from the opinions that I had already formed after dealing with this problem for quite a while now. Breaking away is not easy but it is something I have to do so that the problem will be clearly defined [PhVI/C] (reproduced from Farah's journal).

Discussion

Researchers have observed that the process and outcome of PBL can be uneven and unpredictable (e.g., Mamede et al., 2006; Azer, 2001; Colliver, 2000; Norman & Schmidt, 2000). One reason for this volatility is the lack of detailed understanding of what happens during the collaborative process essential to PBL (Hmelo-Silver & Barrows, 2008; Imafuku & Bridges, 2016; Imafuku et al., 2014). Stahl's (2000) work describing a model of collaborative knowledge building provides an important piece in understanding how knowledge is socially constructed. However, details are still lacking.

This study fills some of the gaps by describing in greater detail the conceptual phases of collaborative interaction in advancing the co-construction of knowledge. The analysis of the participants' interactions during the problem definition stage of the PBL process included all the six phases of mIAM. When all phases were present, the evidence for the co-construction of knowledge was clearer.

The early stage of the interaction mainly revolved around constructing a rich representation of the real-life problem the participants were experiencing. The focus of the initial interaction was on the clarification and justification of ideas and information provided by Farah, based on her knowledge and experience as the principal of the school; therefore, it was not disputed. The social interaction remained within Phase I and II of the mIAM. Initially, the validation of the problem scenario was relatively straightforward as the participants drew upon evidence from existing data from Farah's school. Up to this point, the interaction remained within Phase I and Phase

II of mIAM. It clarified their understanding of the problem with which they were dealing, no evidence existed of the co-construction of meaning and knowledge, as explicated in the eventual mIAM. In fact, as the interaction remained mostly in Phases I and II, the evidence showed that issues discussed were dealt with rather superficially and the dissonances in their thinking were not explored further.

A critical moment which advanced the social interaction beyond Phase II of mIAM occurred when the participants began to explore a myriad of hypotheses regarding the root problem. As they delved deeper into the issue of time constraint as a possible root problem, Jasmin and Farah began to negotiate (Phase III and IV) for a new way of looking beyond the issue of time constraint and started to probe deeper on the issue of skills needed to integrate technological knowledge with pedagogical content knowledge. However, they failed to recognize the significance of this re-framing of the problem after being distracted by another line of discussion. From the standpoint of knowledge construction, the participants' cognitive schemas were still not well-organized and lacked substantiation.

At a later point, the instructor intervened, and through a role-playing discourse, he helped the participants probe deeper. As they began to eliminate potential arguments or relate a number of issues to a root cause, the participants began to build the argument that the reason the teachers did not use technology was because they did not know how to integrate their technological knowledge into their pedagogical content knowledge (Phase III and Phase IV). As their arguments became more concrete, the participants' view of the problem began to shift completely. They had argued earlier that the root cause could possibly be due to reasons such as time constraint or lack of motivation. As the interaction advanced, they began to consider the cause to be teachers who did not know how to integrate their technological knowledge with their pedagogical content knowledge. This shift is evident in their recorded reflections in the journals (Phase VI).

The original IAM (Gunawardena et al., 1997) and the modified IAM from this study provide a more detailed description of the phases of interaction that can lead to co-construction of knowledge. The mIAM was derived from the problem definition phase of a PBL setting and could be valuable to identify further and describe in more detail the interaction phases essential to knowledge co-construction. Further studies on the conceptual phases of interactions in the co-construction of knowledge can help researchers and practitioners in this field to obtain a better understanding of the essential interactional elements that make for productive collaborative talk.

In terms of practice, Hmelo-Silver and Barrows (2008) have argued that such studies can have significant pedagogical implications. The mIAM, for example, can be used as a facilitator's roadmap to scaffold interactions in PBL settings. In this regard, facilitators can use the mIAM roadmap to prepare questions and other scaffolding strategies to help advance the phases of interaction. Facilitators can also use the mIAM as a guide to assess the quality and progress of interaction taking place in their PBL setting. Students in PBL settings can also potentially use the mIAM as a guide to help them become more aware of their own progress in their collaborative interactions.

Before these possibilities for application can be realized, further studies are needed. Because the sample size is small and general conclusions cannot be immediately made, more studies can help deepen our understanding of what takes places during PBL interactions and how it can be improved. Design-based research (DBR) and action research using the mIAM to guide facilitation approaches in PBL settings can also further our understanding about how well such conceptual frameworks can be applied to real-world settings.

Conclusion

This study analyzed the discourse of three participants engaged in the problem definition stage of a PBL cycle. What emerged from the analysis was a modified IAM (mIAM) that can be useful. This model provides a detailed conceptual description of the interaction phases and cognitive activities that represent the flow and advancement of the process of social of construction of knowledge. The analysis of the participants' interactions during the problem definition stage of the PBL process were conceptually represented in six phases in mIAM. The mIAM, with its specific and identifiable phases of cognitive activities, can be useful in conceptually illuminating the movement of the discourse in advancing the social construction of knowledge.

The mIAM, if continued to be verified by other studies, can also add to the research literature (e.g., Hmelo-Silver & Barrows, 2006) for training PBL facilitators on questions to ask that will move the PBL discourse into deeper phases of social construction of knowledge.

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