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Introduction

Computer-supported collaborative learning (CSCL) as a field seeks to understand how shared meaning making unfolds in complex collaborative learning environments that are mediated by technology (Dillenbourg et al. 2009; Suthers 2006). Situating problem-based learning (PBL) in the context of CSCL requires that we understand how available tools and discourse mediate collaborative participation (Hmelo-Silver et al. 2018). A key challenge in understanding the integration of PBL with CSCL environments is to understand the ways that facilitators and students co-construct understanding of the problem space and navigate the complexities of multimodal texts (Bridges et al. 2012; Hendry et al. 2016; Reilly et al. 2019). Thus, the central problem we seek to address is the relationship between multimodal texts and dialogic learning in a cycle of problem-based inquiry. We consider how these relationships develop across times, events, and configurations. These configurations refer to social and material aspects, including actors, material resources, and social and discursive processes. Understanding this relationship also allows us to trace how collective activity is shaped and in turn shapes individual learning trajectories.

We present a conceptual approach to, and the analysis of, developing interactions across a technologically enabled PBL cycle in an undergraduate medical education program. In this study, we present a telling case of an expert medical facilitator engaged with undergraduate students in a PBL cycle (Mitchell 1984). We examined how the facilitator afforded students opportunities for collective and individual interactions with multimodal resources (digital texts, collaborative documents, whiteboard representations, etc.). Specifically, our Interactional Ethnographic (IE) approach examines what was being proposed, recognized, and interactionally accomplished in the moment-by-moment processes as well as in the extended discourse and interactions within and across times, events and configuration of actors engaged in the PBL cycle of learning (Bloome et al. 2005; Green and Bridges 2018; Green et al. 2020). By adopting an IE analytic logic, we lay a foundation for demonstrating how this micro-ethnographic and discourse analytic approach provided a basis for constructing warranted accounts of how multimodal texts shape and are shaped by particular technological, discursive and interactional affordances and patterns of interaction (Castanheira et al. 2000; Heap 1995). In doing so, we expand upon prior sociocultural, video-based studies in CSCL research (Bezemer 2017; Danish 2018; Kershner et al. 2010; Koschmann 1999; Steier et al. 2019a, 2019b). This study was designed to address these interrelationships through the lens of multimodality and social semiotics to consider the relationship between student-generated texts and collaborative learning in technology-supported PBL.

Background: Conceptualizing PBL in technology-supported contexts

In this section, we review two bodies of literature. The first focuses on how CSCL tools were adopted to support problem-based learning processes, and the second explores literature on the role of semiotics in dialogic approaches to blended learning. As the review in this section illustrates, these two bodies of conceptual literature are foundational to our research process as well as to the CSCL field more generally.

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Problem-based learning in computer-supported contexts

Problem-based learning (PBL) is a form of inquiry learning in which students learn in small groups. Guided by the instructor serving as a facilitator of learning. PBL can be described at the levels of educational philosophy, curriculum design, and pedagogic approach (Lu et al. 2014). Philosophically, it aligns with social constructivist designs that foster collaborative problem-solving. As a curriculum design, PBL affords a structure for content integration centering learning around domains, themes, and issues rather than disciplinary silos. At the heart of the pedagogical process is the cycle of inquiry, which is conducted over a period of time. The inquiry phases include first collaborative, facilitated exploration of a newly presented problem, then a phase of independent research, and finally a return to a phase of facilitated sharing, application, synthesis, and reflection (Hmelo-Silver et al. 2019).

Developments in inquiry-based learning designs such as case-based, problem-based and project-based learning have corresponded to the exponential growth of information and access in modern knowledge economies (Chu et al. 2017; Linn et al. 2018; Raes et al. 2013). PBL learning outcomes in clinical curricula focus on promoting skilled and knowledgeable thinkers and clinicians able to draw upon multiple resources in order to deal with ill-defined problems (Barrows 1988). As such, PBL is seen as mirroring and supporting both clinical reasoning and disciplinary research processes. Meta-analyses of studies have established that PBL programs support student learning across disciplinary knowledge, skills and attitudes and encourage deeper approaches to learning (Kim et al. 2018; Prosser and Sze 2014). Problem-based curricula promote long-term retention of knowledge and skills across a range of professional fields and with positive effects seen in workplace contexts (Dochy et al. 2003; Strobel and van Barneveld 2009). Although PBL developed as a low-tech approach to collaborative learning, technology has played an increasing role—ranging from special purpose environments built for the PBL model to general purpose tools that can be used to support the PBL tutorial process (e.g., Lajoie et al. 2020; Ng et al. 2014; Reilly et al. 2019; Verstegen et al. 2016). As such, PBL has been rapidly evolving and is transforming into a new, digitally-connected iteration (see Moallem et al. 2019). A core challenge identified in the literature on emerging roles of technologies in problem-based learning is the perceived blurring and, at times, conflation of the phases of the original PBL cycle. The traditional PBL model had separated phases of facilitator-guided inquiry in face-to-face tutorials with students' independent research during the interim phase/s of self-directed learning. With the advent of ubiquitous access and addition of online resources to case development, students and facilitators have noted a blurring of these boundaries with online searching occurring more routinely within tutorials, particularly in the first phases of problem exploration (Chan et al. 2015). How then, do facilitators help students to manage these new information flows and maintain productive dialogues in problem-based sessions?

Emerging thinking regarding the role of dialogue in learning with technologies centers on Wegerif (2007) conceptualization of "dialogic education" which draws upon the work of Bakhtin (1979/1986) and proposes that "higher order thinking, thinking that is distinctively human, is responsive, creative and unpredictable thinking that originates in dialogues" (pg. 10–11). Taking a dialogic perspective to CSCL allows us to examine how participants coordinate action with and for others, in efforts to understand others as well as to distinguish oneself from others (Koschmann 1999). A focus on the dialogic, therefore, becomes a source of observing thinking in professional education contexts (Frederiksen and Donin 2015; Goodwin 1994), which in turn allows us to examine the nature of collaboration in these contexts.

Finally, attending to processes of online resource appropriation and curation, as well as the development of student-devised digital resources is critical. Student-generated digital resources provide access to, and structure information by embedding expert knowledge and skills in these virtual and technology-enabled face-to-face collaborative sessions (Rasi and Poikela 2016; Savin-Baden 2016). This dialogic process is not only critical to PBL but to the wider issue of digital affordances in inquiry-based learning environments and their influence on joint tasks and resource sharing. Although the contention that learning tools such as visual representations promote student discussion centered on scientific ideas and theories is now widely accepted (e.g., Ainsworth et al. 2011; Cornelius and Herrenkohl 2004), investigations are needed to explore the nature of this close interrelationship between visualizations and dialogic approaches to education, especially in spaces in which new multi-modal technologies are introduced to students (Wegerif 2007; Bridges et al. 2015b). We next consider how multimodality and social semiotics can provide a lens for understanding discursive activity in technology supported PBL.

Multi-modal semiotics and problem-based learning

Before considering how one traces the relationship between multimodal textual development and dialogue in CSCL discourse, we frame this study in terms of the larger field of multimodality (see Jewitt et al. 2016; Kress 2010). First, in considering multimodality from a literacy and social semiotic perspective, Lemke (2009) described

> …multimodal genres as those in which some signifiers are typically interpreted with respect to one semiotic system (e.g., language), and other signifiers that are joined to them syntagmatically are interpreted with respect to another semiotic (e.g., pictorial display). (pg. 286)

This interrelationship between language and image signifiers in meaning-making processes has been explored across a range of disciplines. For example, visual narrative analysts have drawn on Saussure (1916/1983) distinction between the 'syntagmatic' (structural configurations) and 'paradigmatic' (patterns of associations). These distinctions conceived the text user as consciously drawing upon a web of inter-relations to populate and organize sequential relations among elements to form new structural configurations (Wildfeuer and Bateman 2016). Additionally, educational researchers have taken increasing interest in exploring these text-image relations since the paradigm shifting work on 'multiliteracies' by the New London Group (1996), which drew distinct connections between new digital texts and classroom pedagogies. Smith and Kennett (2017) situate multimodality in the processes of learning as intertwined with past and present understandings. They also argue that in blended learning environments, "intentionally designed representational traversals across modes, media, and technologies provide learners consistent scaffolded support along their learning pathways beyond a classroom space" (pg. 91–92).

To understand how learners interact with these scaffolds, researchers in the expanding field of multimodality in the area of scientific concepts have drawn on literacy and social research to provide a grammar and vocabulary for these developing phenomena (Danielsson 2016; Kress and van Leeuwen 2006; Vorvilas et al. 2010. With specific reference to multimodal texts, Bateman (2014) conceptualization of "intersemiotic relations" signals the meaning-making "relations between text and image" (pg. 40). In further considering new semiotic processes in

collaborative inquiry-based learning, Silverstein (2003) concept of "indexical order" also holds salience in that it encourages analysis of "how semiotic agents access macro-sociological plane categories and concepts as values in the indexable realm of the micro-contextual" (p. 193). The CSCL community is also exploring indexicality as related to sequential actions and referential aspects of meaning-making. That is, they have taken interest in exploring how CSCL intersects and/or draws on ethnomethodological studies, for example, on collaborative math problem-solving identifying the role of shared drawings and deictic resources in building intersubjective understandings (Cakir et al. 2009; Zemel and Koschmann 2013). Silverstein (2003) argues that such new semiotic processes have the potential for relational identities to be "creatively (trans)formed in interaction" (pg. 193). Similarly, Iedema (2003) proposed the notion of 're-semiotisation' to trace the unfolding, translational process of unfolding semiotics through social processes and signal how and when they are 'mobilized' (pg. 29). The notion of re-semiotisation holds interest for inquiry-based learning given the centrality of group negotiation processes (Hmelo-Silver et al. 2007). As learners engage with the complexities of problems, a text offered by a group member is then open to the interpretations of others. Whether this text is taken up or not, then becomes a decision of the group's collective problem-solving and reasoning processes.

As this brief overview of the field of multimodal semiotics indicates, examining text-discourse-meaning relations requires new approaches to draw on both spoken and written language as it combines the physically present, in-the-moment with multiple forms of virtual spaces (Suthers 2006). This study builds on prior work in CSCL that examines collaborative problem-solving mediated in synchronous online environments as we address the research question:

> How and in what ways do members of blended PBL tutorials co-construct complex knowledge of proposed medical concepts through intervisual and intertextual dialogic relationships as they engage with a developing series of texts across a PBL cycle of inquiry moment-by-moment and over time?

Methodology, analysis, and the construction of accounts

In this section, we describe a series of analytic processes guided by an Interactional Ethnographic (IE), logic-of-inquiry (Castanheira et al. 2000; Green and Bridges 2018; Green et al. 2020). Our goal in this section is to make transparent how IE supports researchers in developing ways of framing the analysis to construct warranted accounts.

Framing the logic-of-inquiry

In framing Interactional Ethnography (IE) as guided by a micro-ethnographic logic-of-inquiry, we seek to make transparent how, in taking a micro-ethnographic approach to discourse analysis, we extend the work of Jordan and Henderson (1995) in their foundational article. In that article, they argued that "methods, far from neutral tools, promote both concrete working practices and theoretical ideas." (p. 40). Readers familiar with Jordan and Henderson's arguments will see a common set of conceptual assumptions about the social nature of human interaction, and both common and different theoretical grounding for IE as a logic-of-inquiry. At the center of Jordan and Henderson (1995) arguments about Interactional

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Analysis (IA) is the following question: How do people make sense of others' actions as meaningful, orderly, and projectable? This latter concept, they state, draws on Conversation Analysis "to indicate simply that participants in the activities we analyze tend to share common assumptions and embodied practices that allow them to 'project' if not a specific next, a range of likely next occurrences." (p. 41). As evident in the following guiding principles of operation, one major difference for IE's logic-of-inquiry is the researcher's goal of seeking to gain insider (emic) understanding of what supports and/or constrains students in developing particular epistemological processes and disciplinary concepts adapted to educational contexts. These principles are grounded in and adapted from Heath and Street (2008) linguistic/social anthropological perspectives on ethnography, and Agar (2006) view of culture as a verb (see Green and Bridges 2018):

- Suspending known categories to construct understandings of local and situated categories and referential meanings of/for actions being developed by participants and made visible to others in the developing texts of classroom discourse and interactions;
- Acknowledging differences between what ethnographers know and what the actor(s) in the context know, expect, and engage in within and across disciplinary areas of study;
- Constructing new ways of knowing that are grounded in local and situated ways of knowing, being and doing the processes and practices of everyday life within a social group or configuration of actors;
- Developing ways of representing what is known by local actors and what the ethnographers learn from the analysis at different levels of analytic scale.

These principles of conduct constitute an orienting set of goals for the IE study reported here. They also serve to make visible a social constructionist as well as a sociocultural approach to the study of social, cultural, and linguistic phenomena that shape, and are shaped by what participants in particular learning environments count as learning and knowledge (see Fairclough 1992; Heap 1991; Kelly 2016). Given the focus on medical learning opportunities and processes at the center of this study, this work also draws on two foundational research volumes by Mishler (1984) and McClelland and Sands (2001). These volumes, like this IE study, focus on how and in what ways analysis of the discourse-in-use, provide an empirical process for examining what Mishler frames as the "voice of medicine" given that "physicians' control of structure is matched by their control of content. The relevance and appropriateness of information is defined through what physicians choose to attend to and ask about" (p. 95). This argument, as we will make transparent below, is relevant to the way we approached the analysis of the dialogic and multi-modal nature of the medical problem-based learning tutorials, given the goals of the students and the facilitator of developing clinical analytic knowledge and reasoning processes.

IE's transdisciplinary logic-of-inquiry constitutes an orienting theory that guides us in undertaking an iterative, recursive, and abductive approach to analysis (Agar 1994; Agar 2006). It is abductive in that we draw logical inferences from an observation to a theory, which accounts for the observation. It is also iterative and recursive in that one observation in one context can require further exploration of a phenomenon in other contexts. This then can lead us to repeat the processes of joint analysis of archived records with the aim of deeper understanding of the roots and pathways leading to and from co-constructed learning processes. Specifically, in the study reported here, we unfold how and in what ways, under what conditions, and using what past and present resources, configurations of actors propose,

recognize, and interactionally construct local and situated understandings of a pediatric coronary problem. As part of this process, we demonstrate how the IE logic-of-inquiry supports us in identifying key events, what Agar (2006) frames as a 'rich point'; a place where "culture happens", one where the researcher (ethnographer) wonders what is happening and how it came into being. Once identified, these events or observed processes and practices become anchors for tracing backward, forward, and at times sideways, the roots leading to the observed phenomenon.

The identification of these events also supports a process of bounding cycles of activity across times and events and in tracing the students' (individual and collective) learning trajectories in the ethnographic space within and across learning domains (i.e. tutorial sessions and self-directed technology enabled spaces) (see Context below). Through this process, the IE researcher constructs a local and situated logic-in-use that guides entry into archived records as well as multiple levels and phases of analyses. In this way, the researcher also constructs data sets to trace what is proposed, recognized, acknowledged, and interactionally accomplished as socially, academically and (inter)personally significant in purposefully designed educational spaces (Bloome et al. 2005). As such, IE is aligned with studies examining the complex, intersubjective dynamics of computer-supported collaborative learning in-situ and over time.

The IE logic-of-inquiry frames the theoretically grounded process of collecting, archiving, transcribing, and analyzing discourse situated in video and other records of classroom learning as digital and physical artifacts and texts (Baker et al. 2008). These records are constructed within and across contexts and over times and spaces for learning that make possible the construction of understandings of how participants engage in what has been defined as consequential progressions for learning (Lemke 2009; Putney et al. 2000). Our team was guided by the following core principles of conduct for IE studies (Green and Bridges 2018):

1. Constructing telling cases (i.e. identifying what x is a case of that has been previously unknown or in need of further exploration in a particular social domain);
2. (Re)presenting (i.e. making transparent) the reflexive logic-in-use constructed through the iterative, recursive and abductive processes undertaken to trace the developing dialogic processes identified through the construction of transcripts or analyses of texts;
3. Mapping intertextual relations at multiple levels of analytic scale signaled by participants;
4. Making connections between and among what was proposed, recognized, acknowledged and interactionally accomplished by participants that frame what is academically and interpersonally significant through discourse analyses in an intertextual web of activity (i.e. what counts as academically relevant interpretations and information);
5. Identifying patterns of dialogical processes and practices that then form a basis for developing theories by drawing on prior research and past theoretical understandings to construct new theoretical insights and/or to support related bodies of work.

Interactional Ethnography (IE), therefore, enables the research team to step back from what is assumed known to construct a data set that supports tracing through multiple levels of micro-analyses (Green and Bridges 2018; Green et al. 2020; Heath 1982). In applying the above principles of conduct, we created the foundations for constructing a telling case study of undergraduate medical students' building of conceptual understanding of cardiovascular physiology across one PBL cycle (Mitchell 1984; Sheridan et al. 2000) (see below). Through the (re)construction of the analytic processes in which we engaged, we make transparent what constitutes an iterative, recursive and abductive process of tracing the intertextual and

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intercontextual ties among developing events, texts and contexts as well as configuration of actors within the purposefully designed learning events and interactional spaces (e.g., face-to-face tutorials, self-directed learning, and virtual spaces).

Context and telling case selection

At the time of data collection (2015–16), the Hong-Kong based Bachelor of Medicine and Bachelor of Surgery Program (MBBS) adopted a 6-year, systems-based program integrating the undergraduate medical curriculum around major body systems rather than discipline-specific subjects such as, for example, anatomy and physiology. There were nine such system blocks in the first two years of the MBBS curriculum, after the first introductory block in the first semester of the first year. Examples of these system blocks included: the cardiovascular system, the respiratory system, and the gastrointestinal system blocks. There were usually four PBL cases in each of these system blocks. The MBBS curriculum was also designed to be vertically integrated with clinical training and basic sciences in the early and later years respectively, utilizing a hybrid structure with PBL adopted in the pre-clinical years. The PBL model adopted in the telling case study unfolded in the following sections followed the classic PBL cycle of activity (Barrows 1988; Hmelo-Silver 2004) with one facilitator meeting a medium-sized group of students across all four PBL cases in each system block, with two tutorials per case (T1 and T2), each tutorial lasting for about two hours. Some cases also had a third tutorial (T3), which usually lasted for less than 15 min, before the PBL group started their next case. A total archive of 26 PBL tutorials (each lasting for 2–3 h) was recorded in the 6-year Bachelor of Medicine and Bachelor of Surgery (MBBS) program in the period from Semester 2, 2014 to Semester 1, 2017. Given the hybrid nature of the program with PBL adopted in the earlier years, recordings ranged from Years 2–4 of the program and across 81 participants including 9 expert medical facilitators.

For the purposes of the micro-analyses reported here, one Year 2 PBL group and its expert PBL facilitator (n = 12) was selected from the larger archive to form a telling case study (see IE's 1st principle above). This group served as an anchor point for developing theoretically grounded understandings of the complex processes involved throughout the PBL cycle. The selected PBL cycle was the first case in the cardiovascular system 'block', which is the second system block in the first semester of the second year. Total face-to-face sessions in the study's PBL cycle lasted for approximately four hours across a 2-week period in October 2015. The key criterion for selection of this 3-session PBL cycle (T1 - T3) as an anchor for constructing a data set for analysis was to examine how the designed and enacted PBL case and cycle of inquiry involved students in generating and explicating visual texts as a major learning goal. The texts we traced related to a pediatric patient case involving a ventricular septal defect (VSD) - a hole in the wall separating the left and right ventricles of the heart. From the PBL tutor guide for the clinical cardiovascular cases discussed in this cycle, the planned learning outcomes related to visualizations were:

- Draw a labelled diagram of the anatomy of the heart; identify the heart in a chest x-ray and locate the heart chambers on the x-ray image.
- Draw a labelled diagram of the normal cardiac cycle, including intracardiac and arterial pressures, for the systemic and pulmonary circulations; correlate events in the cardiac cycle with heart sounds and surface ECG.

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Across this PBL cycle, students engaged with a range of technologies including mobile devices (7–8 laptops, 1–2 iPad, and 2–5 mobile phones). A laptop connected to a wall-mounted large plasma screen was critical to computer-supported collaboration as the shared display was controlled by the designated PBL group scribe. In terms of digital texts, the group had access to virtual tools such as the in-house Learning Management System (LMS); online search engines and online resources; and Google Docs™ for collaborative text composition. The archived multimodal text types engaged with and invoked by students as shared visual texts embedded in the problem-based, dialogic process of meaning-making ranged from:

- student generated visual representations (whiteboard and PowerPoint drawings and scanned images; shared Google document embedded with searched and copied images; PowerPoint images); to
- curated multimedia and digital texts (anatomical images, video, graphs).

Through a series of unfolding micro and intertextual analyses, the IE analytic team examined the processes that students engaged in with the facilitator to enable our development of theoretical insights into how (re)presenting, a normal cardiac cycle involved a complex set of activities for developing understanding, including comprehension, analysis, and application of anatomy and physiology of the heart. By tracing the moment-by-moment and over time discourse in relationship to multimodal and virtual texts, we sought understandings of complex interrelationships among elements of this dynamic system that framed the need for the concept of dialogic intervisualizing. To develop warranted understanding of this process, we analyzed the PBL video recordings and archived records to examine how the problem design was introduced to the students by the facilitator, and how he engaged students in dialogues using a large number of multimodal texts that were accessed and generated to support their developing understandings of the heart as a dynamic organ. Therefore, this particular PBL cycle formed a purposeful data set for multiple levels of micro-analyses within and across times, events, and configurations of actors to construct accounts and understandings of the ways in which texts were referenced, visually oriented to and reconstructed in the unfolding CSCL discourse and actions of the PBL group's process of inquiry.

Participants and data sources

As noted above, we selected one PBL cycle in the Bachelor of Medicine and Bachelor of Surgery (MBBS) program recorded in the 2nd Semester of the 2015–16 academic year. The consenting group consisted of eleven Year 2 students and their expert facilitator (an anatomy specialist with medical training). A video camera was placed at corner of a small group tutorial room facing the whiteboard and central plasma screen connected to a laptop. Learning artefacts were collected as the problem cycle unfolded both within class and across the intervening and post-cycle self-directed learning (SDL) through stimulated recall interviews. The final ethnographic archive consisted of video recordings of 3 face-to-face tutorials (~2 h each); five student stimulated recall interviews; in-class and out-of-class learning artefacts in the form of PBL case materials (tutor guide and student case notes), student generated group notes (Google Doc), accessed web resources (webpages, videos), and individual resources (PowerPoint files, diagrams). Videos and audio recordings were transcribed; however, transcripts were not viewed as objective and static but rather revisited by the multiple analysts in a recursive, iterative process of video analysis (Bucholz 2000; Putney et al. 2000).

Stimulated recall interviews (SRIs)

Five group members were invited for individual video stimulated recall interviews (SRIs). Selection was based on designated PBL roles, video recordings, and the frequency of interacting with technologies during the ongoing discussion in the first tutorial. The scribe, who was responsible for taking notes of the entire discussion, and the chair, who led the discussion, were invited to participate in both SRIs (one following the first tutorial and one at the end of the problem cycle). Three students who had a high level of interaction with artefacts in the first tutorial were also invited. Two video excerpts from the first tutorial (~15 min each) when one or more students were using educational technologies to support group or individual learning were provided to interviewees as the recall stimuli (Lyle 2003). Students were instructed to pause the video at points of interest and comment on what he/ she was doing or thinking at that time and why. The interviewer also provided additional probes to elicit student thinking processes and subsequent actions. Stimulated recall interviews were recorded and transcribed and added to the archive.

Constructing an IE analytic team

The analytic team was purposefully assembled as was the iterative, recursive, and reflexive process developed for the analyses. The internal ethnographers included two academics with institutional curriculum design, development and MBBS teaching roles. The external ethnographers were international collaborators with expertise in the learning sciences, CSCL, problem-based learning, and educational ethnography. The adoption of these internal-external ethnographer roles supported an interdisciplinary approach as research team members engaged in the ongoing revisiting of the archived records to re-examine learning processes and disciplinary knowledge-building with each perspective contributing new and complementary insights. We began the IE analysis with the selection of the three video recordings of the face-to-face tutorials as anchors for a bounded, focused case study analysis of how students were introduced to and engaged in a dialogic and multi-modal learning process supported by technological resources in the tutorial as well as between the tutorial sessions. Analysis of the classroom artefacts and the SRI interviews complemented the emerging traces from the video analysis and supported development of what constituted consequential progressions that led to new theoretical understandings of the CSCL processes being traced. The ensuing IE event map (Fig. 1) identifies key texts and actors as anchors in the developing PBL process of inquiry and traces the evolution of multimodal text types and learning dialogues as agreed upon and verified by the internal and external ethnographers within the team.

Event mapping to support multiple levels of analysis

A critical process within an IE logic-of-analysis is the construction of a graphic (re)presentation, an event mapping (see IE core principles above). The Fig. 1 event map presents the chronological relationship between texts and talk which assists in identifying how knowledge developed with texts in one context becomes academically and socially consequential to learning across other contexts (Putney et al. 2000). It situates the focused analysis of the three video records of this PBL telling case study in the undergraduate medical education program and identifies the:

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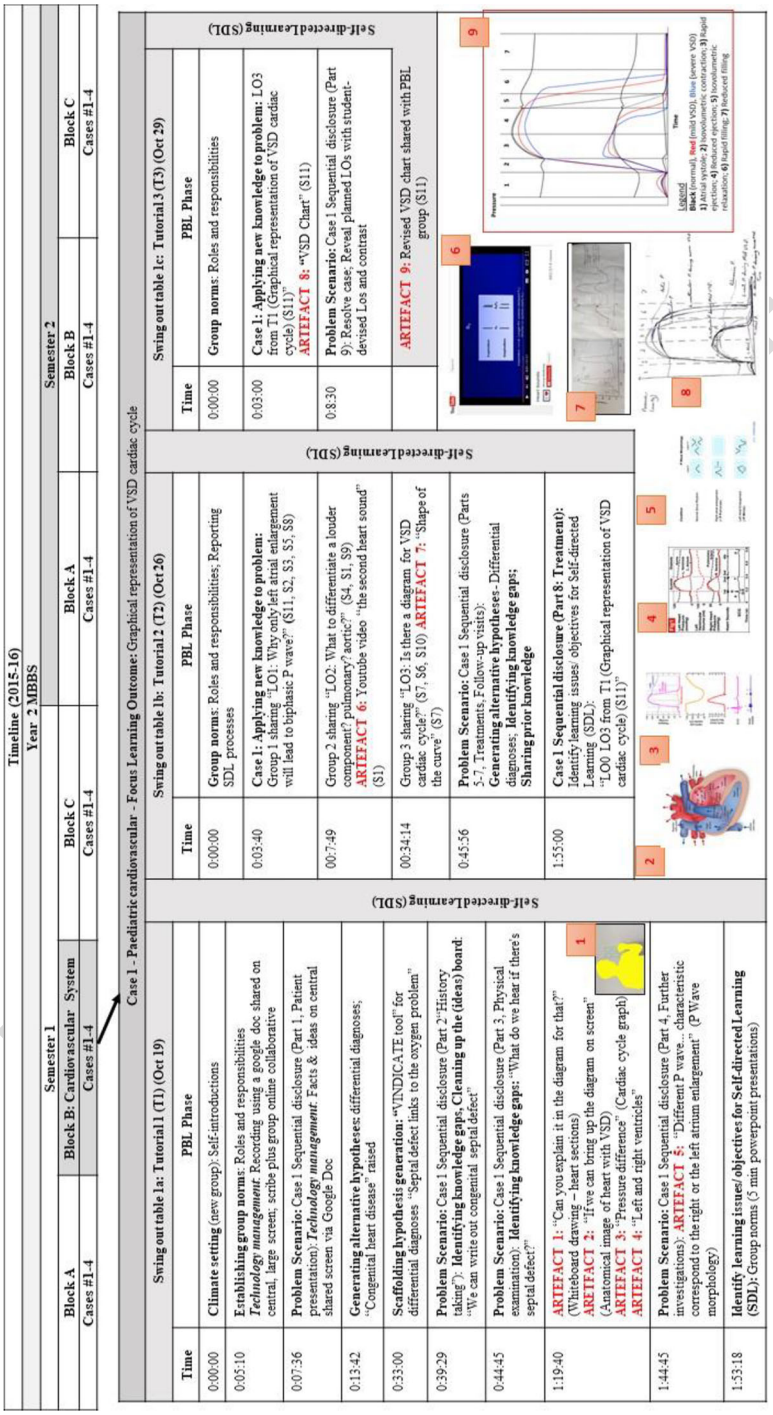

Fig. 1 Event Map: Visualizations across tutorials

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- chains of activity that were developing within and across the designed phases of the PBL cycle of inquiry (both face-to-face tutorials and self-directed learning);
- different sites and times and spaces for learning; and
- evolution of artifacts, key texts and actors in the developing collaborative spaces.

The event map, therefore, provides a basis for exploring multiple part-whole relationships and resources (material, social and academic). Figure 1 illustrates the outcome of our reflexive process of examining the inter-relationships of the evolution of text types and learning dialogues as agreed upon and verified by the internal and external ethnographers within the team.

The first levels of the event map anchor this cardiovascular case discussion (Block B, the cardiovascular block, Case 1) historically in the Year 2 curriculum. Each of the three swing out Tables (1a-1c) in Fig. 1 signify key events and transitions in the PBL process of inquiry anchored to video screen shots or visual artefacts across the three face-to-face PBL tutorial sessions and SRI interviews. This (re)presentation process supported tracing, at the PBL design level, the intervisual development of students' representations of ventricular septal defect (VSD) beginning from Tutorial 1 and Student 11's (S11) initial whiteboard drawing attempt (Artefact 1) to S11's final representation (Artefact 9). In what follows, we trace the key phases of the PBL process of inquiry and map the developing visual texts and emerging discursive argumentation. Selected transcript excerpts of the developing discourse are presented below to indicate the consequential nature of visual Artefacts 1 to 9 (Fig. 1) for student learning in this PBL group. Our approach to transcribing classroom discourse is a form of (re)presenting and tracing the dynamic ebb and flow of the developing discourse as a text as well as intertextual referents (Bakhtin 1979/1986; Bloome and Egan-Robertson 1993; Bloome et al. 2005; Fairclough 1992; Gee and Green 1998; Green and Wallat 1981) (Appendix 1). Drawing on the discourse analysis processes developed by Green and colleagues (Green and Wallat 1981; Kelly and Green 2019), we developed a transcription process to indicate the development of a text from individual message units (bits of talk/speech) marked with a "/". These units combine to make actions, which then combine to make turns at talk, which in turn combine to make interaction units (exchanges between speakers) which combine to make sequence units (topically tied) which combine to make phases of activity, which then combine to make events. An event, therefore, is not a given but a social construction.

In the sections that follow, we progressively unfold different levels of micro-analyses that focus on the development of intervisual ties and actions to provide a basis for theorizing the PBL process within a CSCL system of support. Therefore, through this process of identifying and tracing intervisual ties, we develop a series of warranted accounts of consequential progressions that led to the PBL group's construction of ways of representing the problem under study through the voice of medicine (medical facts and graphic texts) as well as the medical processes through which they were able to understand what was required to conduct a diagnosis of the pediatric heart problem.

Analyses within and across the cycles of inquiry in the PBL process

Our analysis of the development of intervisual ties over time focuses on the CSCL interaction among talk (discourse), gesture, visual and aural information, and kinesthetic and proxemic orientations (Gumperz 1982). In identifying the referential nature of these interactions for the development of individual and group learning, we focus on specific interactional moves in each phase of the PBL cycle that leverage technology-supported intertextuality for group

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Fig. 2 "Can you explain it in a diagram?"

knowledge construction. In what follows, we draw upon IE's 4th core principle of conduct (i.e. making connections through discourse analyses in an intertextual web of activity) to focus on the connection between language and visuals in forming intertextual relations as they unfolded during this MBBS group's problem-based inquiry process. Given our emphasis on student collaboration as mediated by technologies, we trace the way the digital and multimodal texts developed collaboratively within and across the discourse, with a focus on 'intervisual ties'.

The first rich point for tracing intervisual ties between these texts was identified where a student (S11) was asked by a peer (S10) to draw a representation on the whiteboard of the point he was seeking to explain regarding ventricular septal defects (VSD). Figure. 2 provides a de-identified frame extracted from the video recording to illustrate the moment in Tutorial 1 when S11 (standing) responds to the peer request to draw a representation on the whiteboard. The facilitator observing and listening to this exchange is off-screen, behind S11.

To analyze this developing event, we return to Fig. 1 and the chronological relationship between texts and talk, which assists in identifying how knowledge developed with texts in one context becomes academically and socially consequential to the collaborative talk and textual development across other contexts. As indicated in Fig. 1, the first levels of the event map anchor this cardiovascular case discussion (Block B, the cardiovascular block, Case 1) historically in the Year 2 curriculum.

Tutorial 1 – Problem scenario and hypothesis generation

This tutorial involved the sequential disclosure of four sets of new information. In Fig. 1, the first column, swing out Table 1a, indicates key transitions that occur in the problem identification phase of this PBL process. In this phase, the first element of the case was distributed, facts were identified, and students engaged in the process of sharing their prior knowledge as related to the cardiovascular case at hand. Table 1a indicates the rich point at 1:22:45 (see the screen shot in Fig. 1 as Artefact 1 and Excerpt 1) when one student (S11) was prompted by a peer (S10) to attempt to draw a schematic diagram of the heart (Artefact 1). The purpose of this prompt was for S11 to explain his discussion point regarding the formation of heart sounds. The facilitator (F) silently attends to the unfolding discussion.

Excerpt 1 T1 "Can you explain it in a diagram?"

Time T1	Speaker	Transcript of the developing discourse as text (action unit level)	Embodied actions
1:19:40	S10:	Can you explain it in the diagram for that/ I am quite lost actually sorry/	 S10 Turns towards S11 and gestures to whiteboard
	S11:	You know I am terrible in drawing/	 S 11 stands and moves to whiteboard
	S10:	Just draw four/ four squares/ as chambers Sorry/ I am sorry/ I feel quite lost/	 S10 makes circular gesture
	S11:	So it doesn't look like a heart/ it looks weird squares/	 S11 turns to S10
	S10:	Haha/ That's fine/ Just try	 S10 gestures to whiteboard
	S11:	Like/ like/ okay/ so we have the tricuspid valve here right/ And we have the bicuspid or mitral valve here/ ok/ So usually the reason why the pulmonary/ um/ the S2 is splits/ S2 is split is because/ um / it is because the/ it's because the increased venous return to the right side of the heart during inspiration/ right/ because inspiration dilates the superior and inferior vena cava/ right/ I think this is venous return you have more filling in here, so you have like more filling in here, more filling in here relative to relative to the left ventricle/ because the out flow of blood in both ventricles is roughly the same/ right/ so therefore/ um/ the outflow of blood here/ this will take longer to empty the right ventricle/ and the left ventricle since there is less blood/ since there's less blood in it/ it would empty soon/ right/ So that means the B will be closed first/ and then T would be closed later/	 S11 annotates image with text; Group gaze directed to unfolding drawing  S11 Gestures up and down on image to indicate process of emptying
	S8:	But that/ that/ that/ err/ the upper valve/ the upper valve/ not/ not	 S8 and S10 point, jointly correcting S11's error in his description
	S10: S11:	Why T/ not/ not/ Yeah/ err/ Sorry/ I'm sorry/ I'm sorry/ My bad/ my bad/ Yeah/ yeah/ yeah/	
	S8: S11:	Semilunar valve Semilunar valve/ It would lead to the/ um/ it would lead to the aortic valve closing sooner/ and then the/ and then the/ pulmonary/ the pulmonic valve/ closing later on/ ok/ So you get a split/ But/ then/ if we have tricuspid regurgitation/ that means there will be some blood back flowing/ back flowing that way/ so if we have tricuspid regurgitation/ that would/ there is another route for blood flow out from the/ the right ventricle/ And therefore / um/ that should speed up the outflow of blood from the right ventricle/ right/	 S6 & S7 form dyad, gesture between S6's laptop and S11's whiteboard image
	S10:	Oh yeah/	 S11 turns to face S10
	S11:	So/ if it speeds up/the flow of blood/ in the right ventricle/ that means that/	
	S10:	Semilunar valve closes around/ the same time/	 S10 forms spherical shape with hands S11 mirrors briefly
	S11:	Around the same time/ So/ we will have that straight/ right/ But then if it was a mitral valve regurgitation/ then/ there would/ backflow of blood/from the left ventricle/ into the left atrium/ right/ So there would be increase emptying ventricle/	

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As indicated in Excerpt 1, in complying with S10's two-part request, "Can you explain it in the diagram for that" and "just draw four squares", S11 did not speak in complete sentences but rather presented his understanding and interpretation of the diagram (the 4 squares), in message units marked in the transcript by a "/". What this level of analysis made visible was that S11 sought to represent the static structure of the heart, which is a highly specific, as he constructed an abstract representation with the four squares referring to the four chambers of the heart. As he spoke about the text, he made transparent his thinking and understanding of the heart and what was not visible in the drawing through a process of written annotation and gestures to illustrating both spatial and fluid dimensions not evident in his static drawing. The clarification sought by S8 and S10 regarding valves was a key moment. They not only indicated co-construction of knowledge but, by their gestures the generated image, also signaled the centrality of the drawing to their argumentation. This micro-moment and S11's self-correction also prompted associated sub-group activity with S6 and S7 briefly forming a dyad to quietly talk gesture between S6's laptop and S11's image. At the same time, S10 and S11 indicate alignment through talk "oh yeah" and idea completion "semilunar valve closes around the same time" and mirrored hand gestures.

Despite S11's explanation and associated embodied actions, it became clear that the drawing was insufficient to the group's needs in resolving the learning issue of heart sounds as it could not show why the atrioventricular valves shut and produce the first heart sound, and why the semilunar valves (at the bases of the aorta and pulmonary artery) shut and produce the second heart sound ("S2"). Although their side talk was not captured, S7's rebuttal in Excerpt 2 below may be causally inferred as prompted by S11's presentation, S8 and S10's clarification seeking, and his brief side-talk with S6 over her laptop display. The closing of S11's explanation above provided an opportunity for the facilitator (F) to check for understanding with silent group members and provided dialogic space for countering opinions:

Excerpt 2 T1 "I think VSD is not likely

Time T1	Speaker	Transcript of the developing discourse as text (action unit level)	Embodied actions
1:22:16	F:	Do you all follow what ((S11)) was talking about now/	
	S11:	Sorry about the diagram/	
	F:	Is there a better diagram/	
	S11:	/Um/ yes/ but/ it is beyond my ability to draw	
	Sts:	Haha/	
	F:	What diagram/	
	S11:	As in a diagram/ that/looks more like a heart/	S11 Taps image on whiteboard with pen
	All:	Haha	
→	S7:	Actually/	
	F:	Yeah ((S7))	S7 looks down at notes; Members turn gaze to S7
→	S7:	I think/ um/ ventricle/ that/ ventricular septal defect is not likely/	 S7 rubs back of head as lifts head
	S11:	Why/	 S11 sits; S7 drops hand
	S7:	Because/ um/ he has louder/ loud/ a loud pulmonary component/ so this wouldn't explain why the pulmonic component/	 S7 and S11 hold direct line of gaze

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The student group reviewed the shared and reformulated information in light of the candidate diagnosis of (VSD), which was raised an hour earlier in the brainstorming phase (see event map Fig. 1). In Excerpt 2, S7's interjection of "actually" instantly shifted the group's attention. Although initially hesitant, S7 was encouraged by the facilitator to share his thoughts. From his embodied actions in Excerpt 2, he moved from tentatively suggesting VSD as "not likely" as a diagnosis, to gaining confidence in rebutting some of S11's arguments. This confidence was embodied in a physical re-orientation (lifting head from notes; dropping hand from back of head; directing and holding line of gaze with S11) as he offered a counter confounding issue of "loud pulmonary component", which he subsequently expanded upon in depth. Evident in Excerpt 3, below is the key moment where, based on what the facilitator saw and heard in over the past hour of T1 discussion, and at the point of unresolved and conflicting ideas provoked by a S10's request for a visual representation above, he pushed them to seek a "better" diagram. This move keeps the group on track in the developing dialogic process of curating visual images to support their clinical reasoning:

Excerpt 3 T1 "We need a better diagram"

Time T1	Speaker	Transcript of the developing discourse as text (action unit level)	Embodied actions
1:25:35	F:	Well/ I think that is one question/ How/ how do you differentiate whether this is a pulmonic component that is louder/ Um/if we leave that question aside now/ suppose there is a means to/ to find that out that/	
⟹		I think a better diagram can allow everyone to understand / because I think your explanation is very good/ but I think it's only those who already have some understandings/ But I'm not too sure/ cause everyone is quiet/ so I don't know/ how much everyone understands/ we need a better diagram for showing the heart sound/ the flow of blood/	 S11 indicates screen
⟹	S11:	I think he ((S7)) can bring up the diagram on screen/ would be the other one/	
	S3:	Yeah/	
	F:	Which diagram are you talking about/	
	S3:	We don't really have specific/ I mean/ we're just drawing the flow/ to explain/	

As signaled in the key question, in Excerpt 3 above, at this point T1's unfolding discourse, the facilitator's moves supported group dialogic processes. The suggestion to seek another diagram is not only aligned with the group's in-the-moment dialogic reasoning but also to the PBL case's planned learning outcomes (LO) related to visual representations of VSD (see Context above) (Hmelo-Silver and Barrows 2008; Reilly et al. 2019). In this segment of the developing event, what is visible is a challenge facing S11, and by extension other students: Central to the facilitator's suggestion of a better diagram for "showing the heart sound" and the flow of blood is the conundrum of how does one 'show' sound?

The response to this process can be seen in the actions of the participants. This request led to online searching activity by multiple members, indicating the use of a different form of text for the discussion. As a result of this process of online

searching concurrent with the developing line of discussion was the curation and appropriation of S8's offered image (Artefact 2), which was inserted into the Google document and shared via the large plasma screen after the facilitator's prompt of "I saw some of you were actively searching the Internet". However, further analysis of the developing event showed that the search for a digital text was interpreted by some group members as a request for a more anatomically correct and detailed diagram of the heart (Fig. 1, Artefact 2, Excerpt 4). By exploring what was proposed to students by the facilitator and what was recognized and taken up by group members as was visible in their responses (spoken and visual/actions), we trace what was viewed by the facilitator as academically significant to understand and articulate (Bloome et al. 2005). That is, what is indicated in the chain of discourse and engagement with texts, is that students in each phase of the interactions constructed texts through which they attempted to present an anatomically accurate heart that contrasted with the abstract drawing by S11 in Excerpt 1. However, as indicated in Excerpt 4 below, the anatomical image added to the Google document was not 'better' given the facilitator's push for explanation and identification of a better representation of heart sounds:

Excerpt 4 T1 "I don't see the pressure"

Time T1	Speaker	Transcript of the developing discourse as text (action unit level)	Embodied actions
1:27:58	F:	What is actually causing the heart sound formed/	 Facilitator nods towards image (Artefact 2) on screen and shifts gaze across students
	Sts:	Closure/	
	F:	What are driving the closure of these valves/	
	Sts:	Pressure/	
	S6	Pressure difference/	
⟹	F:	Pressure/ and I don't see pressure on this diagram/	
	S2:	The cardiac cycle graph/	
⟹	F:	Yeah/ the cardiac cycle/ picture/ Did you put it on the Google Doc/	

In the exchange above, the facilitator led students to recognize that even this more detailed diagram could not explain the heart sounds since it could not show the changing pressures in different chambers of the heart, which is what causes the closure of heart valves and hence the heart sounds. At that point, S1 searched online, found an image, and displayed a more relevant figure on the cardiac cycle (Fig. 1, Artefact 3 and Excerpt 5). This action led to a major shift in the group's thinking from static visual representations of the heart to focusing on representing the cyclical changes in pressure and volume in different heart chambers through time. It further made visible that from a professional perspective understanding of the cardiac cycle requires understanding of the systolic and diastolic phases, and where these are situated on the visual representation, a process visible in Excerpt 4 and promoted by the facilitator's prior question, "So, can we look at the cardiac cycle?"

However, the image selected only showed the pressure changes on the left side of the heart which was also insufficient to explain the flow through a ventricular septal defect (VSD) because it did not show the pressure difference between the left and the right side of the heart, an important factor determining the flow. Again, the facilitator's questioning drove the students to explore a more complex, and medically correct visual representation:

Excerpt 5 T1 "Do you have a more detailed one?"

Time T1	Speaker	Transcript of the developing discourse as text (action unit level)	Embodied actions
1:34:16	F:	This picture/ doesn't really show you/ the right ventricle/ Do you have a more detailed one/ Both the left/ and the right sides/	 Facilitator directs student gaze to screen and Artefact 3

The growing awareness of what was required is visible in the observed actions of S8, who then searched online and found and shared Artefact 4, which successfully showed the pressure changes of both the left and right side of the heart. However, the problem remained for the case at hand. Our analysis also drew on other classroom artefacts in the form of the group's T1 Google Doc notes which the nominated scribe in T1 contemporaneously composed and displayed during the group discussion. From this we retrieved their recorded question: "Any diagram of VSD cardiac cycle?". This question led to an analysis of the final stage of the sequential disclosure of the pediatric problem for Case 1, an analysis of the results of chest X-ray and echocardiogram tests and led to added discussion of "P wave morphology" (Artefact 5, Excerpt 6) with the P wave being a part in the EKG that indicates the contraction of the atria. The sharing of Artefact 5 leads to identification of left and right but still remains problematic with identified gaps for ongoing research during SDL as indicated in the final exchange on the topic:

Excerpt 6 T1 "But we have a higher peak"

Time T1	Speaker	Transcript of the developing discourse as text (action unit level)	Embodied actions
1:44:45	F:	So/ for right atrium enlargement/ you don't have the biphasic/	 Collective gaze towards screen
	S7:	Yeah/ but we have a higher peak/	
	F:	Which is what ((S5)) was saying/ right/	
	S9:	Yes/	
	F:	So/ why is it only for the left/ the P wave biphasic/ leads to/ Well/ it seems that it may be too complicated a problem/ to solve now/	
	Sts:	Haha	
	F:	You have to go home with some learning issues/ right/	

At the closing of this first tutorial (T1), the group resolved upon three learning objectives (LOs) for research in self-directed learning as listed in the T1 Google Doc and revised in their PPT presentations to read as:

- LO1: "Why does L. atrial enlargement lead to biphasic P waves whilst R. atrial enlargement does not?" ((5 students))
- LO2: "What is meant by "a loud pulmonary component?" ((3 students))
- LO3: "Is there a diagram for VSD cardiac cycle?" ((3 students))

By tracing the chain of discourse and actions of the group in the first tutorial of the PBL cycle, we made visible what was professionally significant to know, understand and do to understand the medical problem. The developing analyses of what was proposed to, recognized by, and

accepted as appropriate texts in Tutorial 1 made the importance of a dialogic approach to understanding textual appropriation and curation visible. Our process of analysis has also progressively disclosed what a situated micro-discursive account made transparent about the dynamics of learning that went beyond simply listing the multiple texts accessed and generated or analyzing their individual properties.

By examining consequential progressions (see principles of conduct above), our analysis has surfaced intertextual progressions that evolved in response to peer and the facilitator's responses to the proffered texts and explanations in this technologically blended PBL tutorial. Each micro-exchange shown in the excerpts and figures presented in this section identified how each dialogic process related to the texts identified, produced and/or searched for, and integrated into the Google document enabled the students to consider which was the best visual representation of the formation and timing of heart sound. As each particular form of representation text was proffered, the group reviewed its relevance to resolving the case at hand.

This chain of evidence from Tutorial 1 is presented the following summary of textual references. It provides a brief (re)construction of what each level of the above analysis made visible and how examination of the intertextual chain of analysis provided an empirical ground for understanding what constituted the knowledge of the medical problem required of the students. The first artefact (Artifact 1) identified foregrounded the causal chain. Depicted as four boxes representing the four chambers of the heart, is a static representation of the anatomy of the heart, albeit with accompanying active gesturing and annotation during S11's explanation. Importantly for the pediatric case at hand, the diagram did not show why the heart valves shut at the appropriate time in the cardiac cycle. Further exchanges in the dialogue between the facilitator and the students led a student to share an even more detailed and anatomically correct diagram of the heart (Artefact 2), but that still did not show how heart sounds are formed since it is still a static representation of the heart. Upon the facilitator's further questioning on the cause of closure of heart valves, students came up with a chart that shows the changes in the pressure and volume of different chambers of the heart within one heartbeat, explaining why the atrioventricular and semilunar valves close at different time points in a cardiac cycle to produce the first and second heart sounds respectively (Artefacts 3–5). Without the dialogue and facilitator's process of orienting students to medical processes and representations, it is unlikely that this new understanding by the group as well as individuals within the group would be possible.

Revisiting tutorial 1 - stimulated recall interviews

However, our analysis did not stop with the video analysis or exploration of texts produced by individuals within the group. To gain further understandings from the perspective of students, as indicated previously, undertook stimulated recall interviews (SRI) with purposefully selected students for additional insights into the thought processes of the group members as they reasoned through the utility of the visualizations for their problem-solving. The conundrum at hand was neatly summarized by the group's T1 scribe (S2) in her recall interview, "Apparently we are all not so sure about the answer whether the pulmonic component or aortic component is louder

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normally." Her peers' stimulated reflections indicate how the explanations generated with and across Artefacts (1–5) supported their own interpretations of the arguments being offered by S11 and S7. For S1, the classroom discussion and searching activity for Artefacts 1–4 "really can't explain the heart sound so I am thinking of cardiac cycle which we have been taught in the lectures". Similarly, S4 was seeking "to correlate with the cardiac cycle and what S7 has just said before." However, S4 was also seeking to integrate the images and S7's sharing with the prevailing differential diagnoses given that the group is considering "two types of possible disease. And one is the VSD, one is the mitral regurgitation". For this student, the process of textual and discursive negotiation is applied to the patient case leading her to

> "think about how the cardiac cycle will be different in different types of the disease. And then if the cardiac cycle is different, then how would the heart sound will be different, and when we're doing the physical examination" (S4 SRI).

Anchoring each stimulated reflection on listeners' thought processes enabled our team to explore the interchange between the visual image, spoken discourse and internal argumentation and reasoning identified in this first face-to-face tutorial session. Interestingly, these interviews differed from traditional post-hoc recall approaches as they were conducted within an unfinished cycle, and so, became part of students' ongoing developing understandings. As per the PBL cycle of inquiry, students then engaged in a period of self-directed learning (SDL) to pursue the three agreed learning objectives above (see Fig. 1).

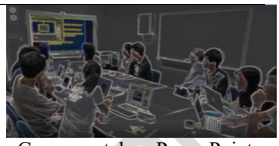
Tutorial session 2: Sharing and applying new knowledge

To further explore the multimodal text and learning discourse relationships identified in the analysis of Tutorial 1, we present our parallel process of analysis of Tutorial 2. In the second tutorial, students reconvened to share their research conducted in self-designated sub-groups and individually during self-directed learning (SDL). This process involved the students in sharing their work in 5-min PowerPoint presentations that were open to interruption by group clarifications. Following the sequential nature of the case design mapped in Fig. 1 (see swing out Table 1b) (Jonassen 2000), the facilitator disclosed three sets of new information pertaining to the development of Case 1 as additional prompts. This also served to meet the learning goal of deeper considerations of biphasic P waves and pulmonary loudness.

Illustrative of the referential nature of learning across a PBL cycle of inquiry, the sharing of SDL information provided the opportunity for students to share additional resources. In the presentations by Group 1, their new resources signaled that the prior visual representations in T1 had been insufficient in meeting agreed upon learning goals. In addressing the raised problem of representing abnormal heart sounds, Excerpt 6 illustrates the moment S1 shared a digital resource that she found (Artefact 6, YouTube™ video at https://www.youtube.com/watch?v=cE8X1nwZWC4). The video embedded in her PowerPoint presentation contained audio recordings of heart sounds in different conditions and reinforced understanding of rhythmic changes in VSD. She then advanced the video to play the recording excerpt relevant to VSD (YouTube™ video segment 07:22–08:36). This audio provided a key stimulus for expanding the groups understanding of heart sounds in a VSD case, and its playing

provided a key moment of joint attention. The PBL group saw this new visual support as relevant and of interest as demonstrated by the shared gaze in Excerpt 7 and request to repeat:

Excerpt 7 T2 "You can hear there is a drop"

Time T2	Speaker	Transcript of the developing discourse as text (action unit level)	Embodied actions
0:20:18	F:	Can you explain/ elaborate what you are hearing/ so that we can hear what you hear/ so that we know what we are hearing/	 Group watches PowerPoint embedded video on screen
	S1:	Err/for the second heart sound/ you can hear that there is a drop/ like for the last part/ it's a bit more/like drop like/ perhaps you can compare it with the louder/ when there is a louder P2/	
	F:	In whatever method/ make them understand/ what you are talking about/ including me/	

Following this new information, the facilitator continued to challenge the students to devise an external, visual representation of heart sounds using the cardiac cycle diagram (a learning outcome from this PBL cycle). This addition of a new resource also indicates a shift in talk where the focus is on visuals that can explain what one is 'hearing'.

In the stimulated recall interview, S11 reveals how his understanding shifted from disagreement with S1 to agreement after thrice listening to the repeated playback of the audio and S1's extended explanation. His initial understanding of the second heart sound was that "it was due to the sudden closure of the semilunar valve, and it was an actual physical impact of the valves on each other that led to the heart sound. And it was also due to the sudden increase of tension in the valve leading to heart sound." He expresses his cognitive conflict as "trying to correlate what she said with my understanding of it." His struggle with reconciling his prior conceptualization with the new digital information and peer argument, led to the 'aha' moment during the second video playing where he "heard the splitting" and could "recognize the difference." At this point, he achieved a new understanding and decided "yes it's time to agree with, with S1 quite there."

Next, during Group1's sharing, a lengthy debate arises regarding S7's hand-drawn graphic embedded as a photograph in the group PowerPoint (See Fig.1 Artefact 7). By the end of the group's descriptive reporting of their SDL findings regarding the mechanical events in the heart with mild and severe VSDs, they recognized that this image may have remained insufficient in meeting the learning objectives of the PBL cycle. The group's final agreement was, as suggested by S11, the student who challenged S7's rationale for Artefact 8, for him to continue researching this unresolved learning issue during independent research in SDL before the third tutorial, naming it LO '0' in the T2 Google Doc notes preceding the additional six new Learning Objectives (LOs) the group had decided upon by the end of the 2-h session.

Tutorial 3 – Resolving knowledge gaps

According to the PBL design of sequential case disclosure evolving across all three tutorials, this tutorial involved the final disclosure of new information that provided

resolution to Case 1 (Fig. 1.). The case learning outcomes were resolved in the first 30 min of Tutorial 3 (T3) before moving to Case 2. In S11's opening sharing of LO '0', which sought to resolve the VSD graph issue, S11 presented several slides of text focusing his argumentation on the differences in shunting between mild and severe VSD. When the facilitator interrupted and pushed for a visual to expand the text-based presentations (Excerpt 8), S11 immediately transitioned to the next slide and shared an original, new graphical representation attempted during SDL and subsequently shared in the third tutorial (T3) (Fig. 1, swing out Table 1c) as an embedded image (Artefact 8). This marked a shift in the students' actions with the integration of visual and aural information into an original image:

Excerpt 8 T3 "I did have a chart of it"

Time T3	Speaker	Transcript of the developing discourse as text (unit level analysis)	Embodied actions
0:8:31	F:	Are you going to have a chart/	 Facilitator gestures to text on screen; S11 taps screen to move PowerPoint to next slide, Artefact 8
	S11:	I did have a chart of it/	
	F:	Would that be easier/ to show it on the chart/ Are you talking about these many changes in pressure and volume/	
	S11:	Yes I tried it	

S11's post-cycle SRI interview reflection of the above T3 presentation illuminates his process of devising Artefact 8. He recognized that S7 had undertaken extensive information searching in the SDL between Tutorials 1 and 2 and had found that the journals were "contradictory". S11 opted for another strategy for his SDL between Tutorials 2 and 3 as "there is no point for me doing more readings. Because the whole LO arose from the fact that I disagreed with what S7 drew… and that I probably wouldn't have found anything extra, that he didn't find or he didn't consider". Significant to the PBL process of inquiry, S11's approach was to provide a final synthesis and he "decided to go using reasoning, instead of doing more research and more reading trying to figure out something." S11's shared representation (Artefact 8) was judged as correct in class but lacking some clarity due to formatting. In excerpt 9, we see how the closure of this T 3 discussion led to the facilitator's closing suggestion for clarification and final achievement of the stated LO:

Excerpt 9 T3 "There are many different curves"

Time T3	Speaker	Transcript of the developing discourse as text (unit level analysis)	Embodied actions
0:13:17	F:	Because I am a very visual person/ and/ for following the relatively complicated process/ I would really benefit from a nicely drawn chart/ and then you explain/ the different parts of the chart/ Since there are many different curves/ the use of different colors would be really useful/ for everyone to take home/ or just for your own record/	 Facilitator maintains gaze to S11 (standing)

In excerpt 9, the facilitator reinforces the need for accurate visual representations but, rather than frame this as a direct critique, opens with a personal learning preference "because I am a very visual person" followed by specific graphic features for academic correction, i.e. different line colors to represent different cardiac events. S11 then undertook to independently produce Artefact 9 (a product developed de novo), to consolidate Case 1 learning across the PBL cycle.

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In the post-PBL cycle interview (see Fig. 1), Student 11 shared the final visual text (Artefact 9) that he had devised and disseminated to the group after T3 and independent of the facilitator. Production of this final artefact became the second rich point identified by the insider ethnographers during a collective video analysis session. The tracing between Artefact 1 and Artefact 9, therefore, became central to our IE micro-analysis.

The analyses presented above illustrate how, by following an abductive, iterative, and recursive approach to drawing upon the multiple records in the archive, the IE logic-of-inquiry draws upon a non-linear process of analysis enabling constant reviewing within and across the ethnographic space (Agar 2006). Medicine is not an individual process but one in which communicating medically relevant interpretations or sharing thinking and problem solving are required elements. Our unfolding analysis illustrates how the PBL design, student engagement with the process of inquiry, and the facilitator's strategies and moves worked together to orient students to particular dimensions of medical knowledge with regard to VSD. We illustrate the way he (re)oriented students to what to consider. In that way, he supported both the individual and the collective, and his stepping back created a process that afforded students opportunities to explore the phenomena in ways similar to the kinds of dialogic events they will encounter in the future diagnostic contexts. This echoes Kumpulainen and Lipponen (2010) prior IE studies in Finnish classrooms, which found the teacher/ facilitator in dialogic inquiry learning designs to be an expert member "evoking ideas and views, scaffolding problem-solving, monitoring and modeling reasoning processes, re-voicing questions and interpretations, promoting collective responsibility, as well as pacing the tempo of interaction" (pg. 60).

Summary: Tracing (inter)visualizations across a cycle of inquiry

The CSCL texts (Artefacts 1 and 9) and their alignment to the PBL goals of collaborative knowledge co-construction became central to creating a dialogic space within and across the face-to-to face tutorials and self-directed learning phases of the PBL cycle. Their generation

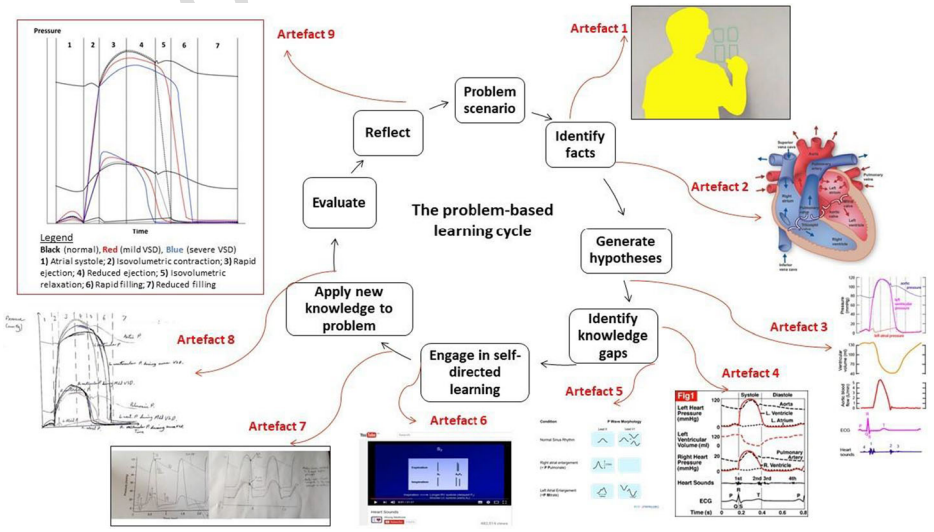

Fig. 3 Intervisualizing across one PBL cycle

opened opportunities for different roles and responsibilities in producing and interpreting texts for computer-supported collaborative learning. Figure 3 illustrates the alignment between the phases of inquiry in the PBL process and the visual texts that were sourced and generated at the prompting of the expert facilitator to address two key learning objectives in Case 1.

Following the PBL learning cycle of inquiry (Hmelo-Silver 2004), students were guided through the non-linear phases of: identifying the dimensions of the problem case; activating their prior knowledge; identifying knowledge gaps for self-directed research; synthesizing information to apply to the case at hand; and evaluating and reflecting on their achievement of PBL learning outcomes and the case-specific objectives. The combined event mapping and tracing of texts and discourse illustrates how the medical facilitator made his medical diagnostic expertise visible through a range of strategic prompts for textual and graphic co-construction, specifically coaching and scaffolding (Collins 2005; Eberle 2018; Hmelo-Silver and Barrows 2008; Lu et al. 2010). In order for S11 and the PBL group to arrive at the purposeful creation of a new text (Artefact 9) as a multimodal affordance for their learning, the group undertook an iterative and recursive process of referential meaning making, orchestrated by their facilitator and taken up by the students, both in class and during self-directed learning. Below, we present a brief overview of the interactions between the facilitator and S11 that shaped Artefact 9:

1. In Tutorial 1, the student peers prompt S11 (Excerpt 1) to produce an image to elaborate on an extended explanation. S6 and S7 briefly form a dyad exploring other screen-based resources before S7 provides counter arguments. S1, S8 and S9 look for images online in response to the discussion and facilitator's prompts and S1 shares the curated images via the large screen.
2. By Tutorial 3, S11 had taken on the challenge to produce "a better diagram" (Artefact 8).
3. S11 further shared this diagram with their group (unbeknown to the tutor) after T3 for their own record (Artefact 9). S11's final produced artefact represents a living text that carries with it prior instantiations and collective understandings. S11 is no longer simply reacting to questions but displays competence in understanding heart sounds.
4. S11's production of the final artefact represents individual-collective-individual efforts in reconstituting and transforming understanding, and as Stetsenko (2013) suggests, "bring(s) forth the world" (pg. 14).
5. S11's post-cycle SRI interview acknowledgement "it's also for my own record" echoes the facilitator's words in T3 (Excerpt 9) and highlights not only how S11's visual representation has changed over time, but also his conceptual understanding.

In summary, the facilitator's goal was for students to understand heart sounds and their relationship to VSD and he employed various strategies to lead the processes of text generation, curation, appropriation and development towards this end. Initially, students' collaborative practices were focused simply on answering questions or 'doing class' at a surface level of text appropriation. In Tutorial 1, S11 was answering questions from a peer as expected of a student and qualified his lack of ability to draw a better diagram. As the facilitator continued to probe and ask questions, students began to initiate online searching, Google Doc™ image and note sharing. The surrounding discourse then focused on curating more appropriate graphic texts, clarifying and hypothesizing as a shared understanding of their collective knowledge gap began to develop (see Point 1 above). By Point 5, we see convergence with the mapping of these computer-supported collaborative interactions across the multiple tutorials being crucial

to understanding S11's conceptual development within the PBL group. In what follows, we highlight and reframe these dialogic processes.

Discussion

Our interdisciplinary research team concurs with Ludvigsen et al. (2018) position in a recent ijCSCL editorial that educational researchers need to examine beyond 'given knowledge' to illuminate how students negotiate content from outside. We also position our work in response to Wise and Schwarz (2017) provocations about the compelling need to make visible the relationship between theory and data. This is especially critical in the context of higher education and CSCL in an era of open access to information. We have sought to make visible text-discourse-learning relationships within and across learning events. Our work is particularly salient for inquiry-based designs such as problem-based learning (PBL) where online information is increasingly being accessed within class rather than segmented chronologically into interim periods of self-directed learning (SDL) and independent research between face-to-face tutorials as in pre-internet PBL. The micro-analysis presented above sought to unpack the complexly intertwined relationships between texts, discourse and collaborative learning in a technology-infused, blended, problem-based learning design in undergraduate medical education. Central to the utility of multimodal perspectives and the theories that inform such perspectives is the key relationship between multimodal texts as they are both produced and interpreted. The 9 artefacts were inscribed by the facilitated PBL group as both generated (drawn) and sourced (searched and curated) multimodal images. By mapping the texts and their associated discourse to the PBL process of inquiry (Fig. 1, Excerpts 1-9), we illustrated the trajectory of this collaborative inscription and indicated how the visual texts align to the computer-supported PBL learning design. In positioning the role of educational ethnography in studies of multimodality, we concur with Flewitt (2011) recommendation to "remain faithful both to the messiness of ethnographic data and the complexity of multimodal communication, while remaining digestible and meaningful for research audiences" (pg. 308). Our video-based ethnography has been both messy and complex but adoption of IE as a logic-of-inquiry has supported both clarity in making visible multimodal processes as well as supporting theory-building.

By tracing the consequential progression of texts in the developing PBL discourse, the IE logic-of-inquiry supports sociocultural research seeking to understand the dialogic relationship between social activity and collective-individual cognitive development in collaborative learning contexts (Derry et al. 2010; DiSessa et al. 2015; Mercer and Howe 2012). By tracing the PBL group's developing knowledge building processes and practices with multimodal texts in a technology-enhanced environment, we aimed to explore the role of these texts in the group's "responsive, creative and unpredictable thinking" (Bloome and Egan-Robertson 1993). We did this by examining the PBL group's developing collaborative reasoning processes by attending to both the extant and developing graphic and visual texts as well as the dialogic text that marked what counts as disciplinary knowledge, and what forms of knowledge counted in the developing collaboration. As noted above, this process aligns with arguments by Frederiksen and Donin (2015) to focus on analysis of what is made visible in the talk/speech and actions.

Our approach builds upon the ontology of interactional sociolinguistics to examine "the dialectic between linguistic signs and social knowledge in discourse" (Rampton 2017, pg. 6).

As such, it has illuminated how the PBL design provided the dialogic space and scope for students to explore and devise a variety of digital texts and visual representations to build collective understanding. This resonates with Airey and Linder (2017) analysis of representations and group meaning making in university physics classes, which found that semiotic resources provide a "range of disciplinary meaning potentials" (pg. 99). Lemke (1998) foregrounded this complex interplay between texts and contexts and viewed meaning as "multiplicative" rather than "additive" implying the exponential and diverse possible meanings that are available to "make the whole far greater than the sum" (pg. 312). The ethnographic tracing above illustrated the multiplicative potential of the various texts invoked by group members. It also illustrated an intervisual process of drawing, accessing, curating, appropriating and re-creating in the facilitated PBL group dialogue. Given our focus on the reasoning processes fostered in a PBL cycle of inquiry, we traced preferential information selection and the connections made between and among texts as collective knowledge was building through the discourse and actions of participants. What became evident though the micro-analyses of the discourse and texts was the cumulative, consequential nature of the dialogic process. The collaborative talk became inextricably intertwined with the intervisual ties within and across the PBL cycle as the group strove towards their goal of capturing the key concepts of ventricular septal defect (VSD) represented in Artefact 9. As such, this study further expands upon CSCL research into how multimodal representations contribute to collaborative meaning-making and the sequential production of texts (Steier et al. 2019a, 2019b; Zemel and Koschmann 2013).

Additionally, we provide textured, nuanced evidence of what Suárez et al. (2018) review of learner agency and mobile activities in inquiry-based learning described as a dynamic approach to accessing content In such an approach, learners exercise intrinsic control "to browse, filter, retrieve, evaluate, and interpret" resulting in the integration of new information "to support ongoing observations and to create new knowledge in the physical environment integration of contextually relevant information" (ibid pg. 43–44). Their recommendation of developing students' digital literacy skills in information filtering and analysis as central to interpreting content sourced from mobile devices is supported by our team's analysis above. Given the centrality of digital and information literacy to these new ways of textual negotiation within face-to-face PBL dialogues, the findings of this study have expanded understandings of the relationship between multimodal texts and semiotic processes of knowledge co-construction in higher education. Like Glazewski and Hmelo-Silver (2019), we recommend support for students in what they term ambitious learning practices considering the levels of complexity and information literacy demands that the accessing of such texts requires. As such, this study's findings support work in the learning sciences on learner-constructed inscriptions which conceptualize "representational practices as embodying strategies for constructing, manipulating and interpreting inscriptions" (Medina and Suthers 2013, pg. 34). The 9 artefacts that were inscribed by the expert facilitated PBL group as both generated and sourced multimodal images and mapped to the phases of PBL inquiry and their associated discourse form a co-constructed, intervisual web of meaning making within and across the PBL learning cycle (Fig. 3). The mapping and micro-analyses above illustrated how both the social and the cognitive dimensions of learning can be traced as intertwined chains of action, discourse and multimodal texts that are locally and collaboratively constituted and re-constituted as they are guided and scaffolded by an expert facilitator in an iterative, recursive inquiry-based process of learning.

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Capturing and analyzing the nuanced processes of verbal and physical collaborative learning interactions with CSCL tools is a complex process (Martinez-Maldonado et al. 2013). The Interactional Ethnographic (IE) approach adopted in this study has uncovered the facilitation strategies supporting a process of multimodal text development from generation and identification to critique and curation followed by refinement and an ongoing process of (re)production. It has also provided the opportunity to examine, to a much smaller extent, what students do in the independent, self-directed phase of the PBL cycle. Our specific goal was to explore how digital texts came into being through the processes of information searching and synthesis. In the telling case study above, we identified how meaning-making is supported through the building of ties between graphic representations and the discursive construction of a collaborative learning context supported by educational technologies. In such a rich context, multimodal texts in the form of technologically-supported visualizations (digital learning objects, webpages, collaborative online tools) are employed to support the clinical reasoning processes central to the PBL approach. From a social semiotic perspective, what was eventually appropriated and curated from the texts that were accessed and retrieved in the case analysis above became central to a causal chain of dialogic reasoning, which we propose as a process of dialogic intervisualizing.

Defining dialogic intervisualizing

In considering the dialogic process presented in the sections above, we build upon Wegerif (2007) proposed "vision of education as induction into dialogue" with educational technologies as a "tool for opening up and resourcing the kind of dialogic spaces that enable people to think, learn, and play together" (pg.7). Evident from this IE study of medical problem-based learning in a blended learning environment is the unique nature of the dialogic space formed by a technology-enhanced approach to facilitated inquiry. While the empirical bases for Wegerif (2007) theory-building are schools, this study of PBL in university undergraduate medical education provides a nuanced understanding not only of student agency and autonomy in navigating digital information flows in a more open and fluid form of small, group problem-based inquiry, but also the centrality of the expert medical facilitator in guiding the process of textual development for, in this case, clinical reasoning processes including visual textual generation, selection, critique, curation and final appropriation.

We propose that, in naming the key phenomena as the concept of dialogic intervisualizing, it situates both the event and textual processes, i.e. the developing composition and a meta-discursive set of orienting signals and processes. This is particularly important for CSCL because it begins to provide a new language for the complex learning processes evident in the negotiation of shared understanding and intersubjective meaning making as it is mediated by talk and texts in CSCL environments. Our concept builds upon the historical origins of intervisuality in art history to embrace textual navigation in a digital era (Burke 2007). We also expand the conceptualization of the intervisual as an adjective to the notion of visualizing as a verb, central to the reasoning processes of dialogic learning contexts such as PBL. Our argument for this reconfiguration of dialogic with intervisualizing also builds on Lemke (2009) arguments regarding timescales and the analysis of the complexity of classrooms as "ecosocial systems". Taking the above telling case study as a ecosocial system, we can see how meaning-making in the inquiry-based context was supported through the building of discourse ties

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between graphic representations as visual, often digital, multimodal 'texts' and the actions proposed or made transparent by members within and across the timescale of one PBL cycle. As such, dialogic intervisualizing characterizes the dynamic interplay between and among information problem-solving processes, textual negotiations and purposeful, facilitated dialogue for deep knowledge co-construction within and across collaborative, computer-supported learning activity in an inquiry cycle. Therefore, we define dialogic intervisualizing as a process of facilitated collaborative inquiry involving discursively negotiated navigation of in-the-moment and over time accessed, curated and devised digital information and visual representations which evolve through socially and cognitively intertextually tied webs of meaning-making.

So then, what can this construct contribute to the CSCL community? Dialogic intervisualizing has key implications for CSCL learning, design and analysis. For CSCL learning, dialogic intervisualizing goes beyond a teacher providing an image as a cognitive prompt or a matter of asking students to create a visual as a product to support their explanation. Rather, we view it as situated within a collaborative process of facilitator guided, scaffolded inquiry that explores the dimensions of a complex problem with an ultimate goal of developing reasoning skills for applied problem-solving. In doing so, it recognizes the cumulative, referential, and sometimes recursive, nature of learning with multiple multimodal texts supporting the building of understanding over time and across contexts. As such, dialogic intervisualizing also calls on student agency to question, explore, synthesize, apply and create. For CSCL design, dialogic intervisualizing is part of the explicit scaffolding of a technology-enhanced problem design in which learning outcomes dictate that a graphic will be generated. It recognizes that multimodal, and particularly visual digital, texts are embedded in CSCL inquiry-based designs as these texts become referentially tied to each through information accessing, curation and modification.

Implications in facilitating and designing for dialogic intervisualizing

This study provides a detailed illustration of how undergraduate medical students and their facilitator incorporate visualizations to support a disciplined perspective of the groups' collaborative sense-making. We offer several guidelines that may support the design for computer-supported collaborative learning.

Encouraging sharing of known forms of disciplined-based representations

In our work, we have demonstrated that centering learning on a particular phenomenon can be supported by discipline-based representations. This group of medical students, for instance, referred to several representations of the heart, ranging from simplistic depictions and anatomically correct diagrams to discipline-specific representations such as the cardiac cycle. The availability of these representations in addition to the growing expertise of the medical students is highlighted in the evolution of their thinking. This supports prior literature that indicates that students may shift between different levels or forms of representations and that these various forms are critical to support understanding (Ainsworth 2014; Danish et al. 2017). It is critical for learners to take advantage of the differences and types of information that are available to them via these representations.

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Leveraging multiple modalities to support disciplinary learning over time

With the advent of technology, representations can often be multimodal and indeed, in some cases, may be necessary to support collaborative problem-solving. In our work, it has been demonstrated that students sometimes realize that constrained or purely visual representations are not sufficient to solve a problem. These situations can then be addressed by leveraging aural or verbal sources of information. Multimodal resources can accompany discipline-based visual representations, but only after students recognize the need to support their initial comprehension of prior information (Rummer et al. 2011). Moreover, by acknowledging the multimodal nature of digital information accessing and sharing, students can also be taught to be sensitive to the gestures that accompany their talk. The complexities of representations in computer-supported collaborative discourse in particular might benefit from allowing students to develop their understanding of a phenomenon over time. More importantly, it is the historicity and evolution of the representations that highlight how students appropriate sourced information. As Tchounikine (2019) pointed out, these acts of appropriation highlight students' agency in the nature of collaborative learning.

Developing models of dialogue around discipline-based representations

Our work echoes findings from prior scaffolding work that highlights the importance of integrating representations that are organized around the semantics of the discipline (Kelly and Green 2019; Quintana et al. 2004; Tang and Danielsson 2017). However, it is not sufficient to simply provide students with discipline-based representations. Rather, it is crucial to establish a joint task or common goal that fosters the co-construction of knowledge and to support this discursively. In the CSCL community, these discursive supports can take the form of scripts, or scenarios that support collaborative learning by providing activities that may or may not constrain modes of interaction among learners. We take the position that while computer-supported scripts might be invaluable to support learning, there is much to be learned from the ways that a more knowledgeable tutor interacts with groups of students. Indeed, subtle interactional moves in discourse often support noticing of phenomena. Like Wise and Schwarz (2017), we argue that a combination of learner agency and knowledgeable tutors are critical to informing models of collaborative learning. Given the corpus of verbal and written dialogue acts, interactions around discipline-based representations offer important avenues for understanding how we might automatically tag dialogue acts so that we are better able to support interactional moves.

Conclusions

Computer-supported collaborative learning (CSCL) environments lie in the intersection between robust pedagogies and technology (Yoon and Hmelo-Silver 2017; Stahl et al. 2014). One key challenge in understanding CSCL environments is how to study the ways that facilitators/teachers engage students in navigating the complexities of digitally constructed texts in information-based problem solving sessions (Jeong and Hmelo-Silver 2016). This has become especially salient as CSCL researchers have sought to understand the nature of the collective coordination and co-construction of new forms of information and texts. Related to

the first challenge are the various methodological approaches that can be adopted to analyze interactions in CSCL environments. Wise and Schwarz (2017), for instance, noted that a core issue in interpretive analysis is the lack of integration between theoretical concepts such as how learning occurs (i.e. appropriation) and the mapping of such concepts to an analysis of collaborative learning as it unfolds. One of our goals is, therefore, to respond to their provocation by providing an interpretive account of collaborative thinking in interaction and across inquiry-based events to offer a systematic and theory-rich approach to analyzing discourse in context.

To sum up, this study has identified the nuances of intersubjective sense-making in the facilitated interpretation and production of multimodal texts within and across the technology-enhanced dialogic space that constitutes a modern problem-based learning (PBL) cycle of inquiry. We propose this to be conceived as a process of dialogic intervisualizing which broadens the conceptualization of dialogic learning and social semiotic conceptions of intervisuality at their point of intersection in inquiry-based learning designs in CSCL environments. As such, dialogic intervisualizing characterizes the dynamic interplay between and among information problem-solving processes, textual negotiations and purposeful, facilitated dialogue for deep knowledge co-construction within and across collaborative, computer supported learning activity in an inquiry cycle. Taking the stance that learning occurs within and "across the scales of time" (Lemke 2000, pg. 288), adoption of an Interactional Ethnography (IE) provided a logic-of-inquiry to examine the consequential nature of the in-the-moment and over time coordinated learning activity of student meaning-making processes with multimodal texts. Our approach aligns with recent work on developing a micro-ecological framework for CSCL to address the issue of scalability in studies of situated learning (Borge and Mercier 2019). Given that inquiry-based learning designs are evolving and reformulating in a digital era of ubiquitous access to information and multimodal texts, new challenges arise for teacher facilitation and orchestration (see Roschelle et al. 2013). This is an area of important future research and professional development, especially if we are to hold to the principle that dialogic education is central to inquiry-based learning.

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Appendix 1. Transcribing developing texts: Operating principles

Guided by Bucholz (2000) argument that, in the process of transcribing, the researcher constructs the "other", i.e. the people in interaction, we turn to a brief description of the analysis system that grounded our tracing of the developing talk, discourse, interactions and activity. The transcription process is guided by the sociolinguistic approach of Gumperz and Herasimchuk (1972) that framed the concept of contextualization cues in the construction of meaning. This argument was adapted by Green and colleagues (Green and Wallat 1981; Kelly and Green 2019) to show the developing texts of classroom talk. These cues include: pitch, stress, pause, juncture, kinesics, proxemics, gesture, eye gaze, lexicon and grammar, which signal meanings to participants. Adding Fairclough (1992) argument, we see that each

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utterance is a tripartite process: a text, a discourse practice and a social process, or a saying, a making, and a doing of interaction. He further argues that when a text is proposed, what happens next is shaped by the utterance/discourse practice/social process and in turn shapes what occurs next. These conceptual arguments converge with, and yet differ from, other forms of discourse analysis (e.g., conversation analysis, i.e. the Jeffersonian Transcript; see also Cameron 2001). This approach to transcription provides a grounding for tracing the developing instructional text (i.e. the PBL case design) and for identifying developing textual and intertextual information being referenced and oriented to by participants.

Bloome et al. (2005) framed the following logic central to this approach to analyzing the developing texts. They argued that in interaction, participants propose, recognize, and interactionally accomplish what is significant to know, understand and do in this event. Through this process, participants construct not only academic information but also identities, social relationships, textual relationships as well as power relationships. Underlying Bloome et al. (2005) and guiding an IE logic-of-analysis is Bakhtin (1979/1986) argument about speaker-hearer relationships that:

> Sooner or later what is heard and actively understood will find its response in the subsequent speech or behavior of the listener. In most cases, genres of complex cultural communication are intended precisely for this kind of actively responsive understanding with delayed action. Everything that we have said here also pertains to written and read speech, with the appropriate adjustments and additions (pg. 69).

Based on these theoretical frameworks and the understanding among these theorists of speech/discourse, we further recognize that, in these developing moments, there are traces of other texts that form the need to trace the histories of these developing understandings across times, events and configurations of actors in particular cycles of learning. That is, as Bakhtin 1979/1986, pg. 84) argued, "Any utterance is a link in a chain of speech communication." Included in the excerpts are also hesitation phenomena and repeated bits of talk that make visible the speaker as hearer and how the speaker is monitoring their own talk. This aligns with arguments by Frederiksen and Donin (2015) that analysts (and by extension hearers) cannot see into the head of speakers but rather can only analyze what is made visible in the talk/speech and actions.

References

Agar, M. (1994). *Language shock: Understanding the culture of conversation*. New York, NY: Quill.

Agar, M. (2006). An ethnography by any other name … Forum Qualitative Sozialforschung / Forum: Qualitative Social Research, 7(4). http://nbn-resolving.de/urn:nbn:de:0114-fqs0604367.

Ainsworth, S. (2014). The multiple representation principle in multimedia learning. In R. Mayer (Ed.), *The Cambridge handbook of multimedia learning*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.024.

Ainsworth, S., Prain, V., & Tytler, R. (2011). Drawing to learn in science. *Science, 333*(6046), 1096–1097.

Airey, J., & Linder, C. (2017). Social semiotics in university physics education. In D. Treagust, R. Duit, & H. Fischer (Eds.), *Multiple representations in physics education* (pp. 95–122). Cham: Springer.

Baker, W. D., Green, J., & Skukauskaite, A. (2008). Video-enabled ethnographic research: A microethnographic perspective. In G. Walford (Ed.), *How to do educational ethnography*. London: Tufnell Press.

Bakhtin, M. M. (1979/1986). Speech genres and other late essays (V. W. McGee, Trans.). Austin: University of Texas Press.

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Barrows, H. S. (1988). *The tutorial process*. Springfield, IL: Southern Illinois University Press.
Bateman, J. (2014). *Text & image: A critical introduction to the visual/verbal divide. London*. New York: Routledge.
Bezemer, J. (2017). Visual research in clinical education. *Medical Education, 51*(1), 105–113. https://doi.org/10.1111/medu.13163.
Bloome, D., & Egan-Robertson, A. (1993). The social construction of intertextuality in classroom reading and writing lessons. *Reading Research Quarterly, 28*(4), 304–333.
Bloome, D., Carter, S. P., Christian, B. M., Otto, S., & Shuart-Faris, N. (2005). *Discourse analysis and the study of classroom language and literacy events: A microethnographic perspective*. Mahwah, NJ: Lawrence Erlbaum Associates.
Borge, M., & Mercier, E. (2019). Towards a micro-ecological approach to CSCL. *International Journal of Computer-Supported Collaborative Learning, 14*(2), 219–235.
Bridges, S. M., Botelho, M. G., Green, J., & Chau, A. C. M. (2012). Multimodality in PBL: An interactional ethnography. In S. M. Bridges, C. McGrath, & T. L. Whitehill (Eds.), *Problem-based learning in clinical education: The next generation* (pp. 99–120). Netherlands: Springer.
Bridges, S, M., Corbet, E, F., Chan, L, K. (2015a). Designing problem-based curricula: The role of concept mapping in scaffolding learning for the health sciences. Knowledge Management & E-Learning: An International Journal, 7(1).
Bridges, S. M., Green, J. L., Botelho, M. G., & Tsang, P. C. S. (2015b). Blended learning and PBL: An interactional ethnographic approach to understanding knowledge construction in-situ. In A. Walker, H. Leary, C. E. Hmelo-Silver, & P. A. Ertmer (Eds.), *Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows*. Illinois: Purdue Press.
Bucholz, M. (2000). The politics of transcription. *Journal of Pragmatics, 32*, 1439–1465.
Burke, P. (2007). *Eyewitnessing: The uses of images as historical evidence (picturing history)*. London: Reaktion Books.
Cakir, M. P., Zemel, A., & Stahl, G. (2009). The joint organization of interaction within a multimodal CSCL medium. *International Journal of Computer-Supported Collaborative Learning, 4*(2), 155–190.
Cameron, D. (2001). *Working with spoken discourse*. London: Sage.
Castanheira, M. L., Crawford, T., Dixon, C. N., & Green, J. L. (2000). Interactional ethnography: An approach to studying the social construction of literate practices. *Linguistics and Education, 11*(4), 353–400.
Chan, L. K., Bridges, S. M., Doherty, I., Ng, M. L., Sharma, N., Chan, N. K., & Lai, H. Y. Y. (2015). A qualitative study on how health professional students and their PBL facilitators perceive the use of mobile devices during PBL. *Interdisciplinary Journal of Problem-Based Learning, 9*(1), 83–95.
Chu, S. K. W., Reynolds, R. B., Tavares, N. J., Notari, M., & Lee, C. W. Y. (2017). *21st century skills development through inquiry-based learning: From theory to practice*. Singapore: Springer Science.
Collins, A. (2005). Cognitive apprenticeship. In R. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 47–60). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511816833.005.
Cornelius, L. L., & Herrenkohl, L. R. (2004). Power in the classroom: How the classroom environment shapes students' relationships with each other and with concepts. *Cognition and Instruction, 22*, 467–498.
Danielsson, K. (2016). Modes and meaning in the classroom – The role of different semiotic resources to convey meaning in science classrooms. *Linguistics and Education, 35*(supplement C), 88–99. https://doi.org/10.1016/j.linged.2016.07.005.
Danish, J, A. (2018). Designing for technology enhanced activity to support learning, The Emerging Learning Design Journal, 1(1), article 1.
Danish, J., Saleh, A., Andrade, A., & Bryan, B. (2017). Observing complex systems thinking in the zone of proximal development. *Instructional Science, 45*(1), 5–24.
Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., Rogers, H., Koschmann, T., Lemke, J., & Sherin, M. G. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *The Journal of the Learning Sciences, 19*(1), 3–53.
Dillenbourg, P., Järvelä, S., & Fischer, F. (2009). The evolution of research on computer- supported collaborative learning. In N. Balacheff, S. Ludvigsen, T. Jong, A. Lazonder, & S. Barnes (Eds.), *Technology-enhanced learning* (pp. 3–19). Dordrecht: Springer Netherlands.
DiSessa, A. A., Levin, M., & Brown, N. (2015). *Knowledge and interaction: A synthetic agenda for the learning sciences*. New York: Routledge.
Dochy, F., Segers, M., Van den Bossche, P., & Gijbels, D. (2003). Effects of problem-based learning: A meta-analysis. *Learning and Instruction, 13*(5), 533–568.
Eberle, J. (2018). Apprenticeship learning. In F. Fischer, C. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 44–53). New York: Routledge, Taylor & Francis.
Fairclough, N. (1992). Intertextuality in critical discourse analysis. *Linguistics and Education, 4*(3–4), 269–293.

JrnlID 11412_ArtID 9328_Proof# 1 - 28/08/2020

Flewitt, R. (2011). Bringing ethnography to a multimodal investigation of early literacy in a digital age. *Qualitative Research, 11*(3), 293–310.

Frederiksen, C. H., & Donin, J. (2015). Discourse and learning in contexts of educational interaction. In N. Markee (Ed.), *The handbook of classroom discourse and interaction* (pp. 96–114). West Sussex: John Wiley & Sons, Inc..

Gee, J. P., & Green, J. L. (1998). Discourse analysis, learning, and social practice: A methodological study. *Review of Research in Education, 23*, 119–169.

Glazewski, K., & Hmelo-Silver, C. (2019). Scaffolding and supporting use of information for ambitious learning practices. *Information and Learning Sciences, 120*(1/2), 39–58. https://doi.org/10.1108/ILS-.

Goodwin, C. (1994). Professional vision. *American Anthropologist, 96*(3), 606–633.

Green, J. L., & Bridges, S. M. (2018). Interactional ethnography. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 475–488). NY: Routledge.

Green, J., & Wallat, C. (1981). Mapping instructional conversations-sociolinguistic ethnography. In J. Green & C. Wallat (Eds.), *Ethnography and language in educational settings* (pp. 161–208). Norwood, NJ: Ablex.

Green, J., Baker, W. D., Chian, M. M., Vanderhoof, C., Hooper, L., & Kelly, G… & Kalainoff, M. (2020). Studying the overtime construction of knowledge in educational settings: A microethnographic-discourse analysis approach. *Review of Research in Education., 44*(1), 161–194.

Gumperz, J. J. (1982). *Discourse strategies* (Vol. 1). New York: Cambridge University Press.

Gumperz, J. J., & Herasimchuk, E. (1972). The conversational analysis of social meaning: A study of classroom interaction. In R. Shuy (Ed.), *Sociolinguistics: Current trends and prospects*. Washington, D.C.: Georgetown University Press.

Heap, J. (1991). A situated perspective on what counts as reading. In C. Baker & A. Luke (Eds.), *Towards a critical sociology of reading pedagogy* (pp. 103–139). Philadelphia, PA: John Benjamins.

Heap, J. L. (1995). The status of claims in "qualitative" educational research. *Curriculum Inquiry, 25*(3), 271–292.

Heath, S. B. (1982). Ethnography in education: Defining the essentials. In P. Gilmore & A. A. Glatthorn (Eds.), *Children in and out of school: Ethnography and education (pp. 33-55)*. Washington, D.C: Center for Applied Linguistics.

Heath, S. B., & Street, B. V. (2008). *On ethnography: Approaches to language and literacy research*. New York: Teachers College/NCRLL.

Hendry, G., Wiggins, S., & Anderson, T. (2016). Are you still with us? Managing mobile phone use and group interaction in PBL. *Interdisciplinary Journal of Problem-Based Learning, 10*(2).

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*(3), 235–266. https://doi.org/10.1023/B:EDPR.0000034022.16470.f3.

Hmelo-Silver, C. E., & Barrows, H. S. (2008). Facilitating collaborative knowledge building. *Cognition and Instruction, 26*(1), 48–94.

Hmelo-Silver, C. E., Katic, E., Nagarajan, A., & Chernobilsky, E. (2007). Soft leaders, hard artifacts, and the groups we rarely see: Using video to understand peer-learning processes. In R. Goldman, R. D. Pea, B. J. S. Barron, & S. J. Derry (Eds.), *Video research in the learning sciences* (pp. 255–270). Mahwah NJ: Erlbaum.

Hmelo-Silver, C. E., Kapur, M., & Hamstra, M. (2018). Learning through problem solving. In F. Fischer, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 210–220). New York: Routledge.

Hmelo-Silver, C. E., Bridges, S. M., & McKeown, J. (2019). Facilitating problem-based learning. In M. Moallem, W. Hung, & N. Dabbagh (Eds.), *Wiley handbook of problem-based learning* (pp. 297–320). NY: John Wiley & Sons, Inc..

Iedema, R. (2003). Multimodality, resemiotization: Extending the analysis of discourse as a multisemiotic practice. *Visual Communication, 2*(1), 29–57.

Jeong, H., & Hmelo-Silver, C. E. (2016). Seven affordances of computer-supported collaborative learning: How to support collaborative learning? How can technologies help? *Educational Psychologist, 51*(2), 247–265.

Jewitt, C., Bezemer, J., & O'Halloran, K. (2016). *Introducing multimodality*. London and New York: Routledge.

Jonassen, D. H. (2000). Supporting problem solving in PBL. *Interdisciplinary Journal of Problem-Based Learning, 5*(2), 95–119.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences, 4*(1), 39–103.

Kelly, G. J. (2016). Methodological considerations for the study of epistemic cognition in practice. In J. A. Greene, W. A. Sandoval, & I. Braten (Eds.), *Handbook of epistemic cognition* (pp. 393–408). New York: Routledge.

Kelly, G. J., & Green, J. L. (2019). *Theory and methods for sociocultural research in science and engineering education*. NY: Routledge.

Kershner, R., Mercer, N., Warwick, P., & Staarman, J. L. (2010). Can the interactive whiteboard support young children's collaborative communication and thinking in classroom science activities? *Computer Supported Learning, 5*(4), 359–383. https://doi.org/10.1007/s11412-010-9096-2.

Kim, N. J., Belland, B. R., & Walker, A. E. (2018). Effectiveness of computer-based scaffolding in the context of problem-based learning for STEM education: Bayesian meta-analysis. *Educational Psychology Review, 30*, 397–429. https://doi.org/10.1007/s10648-017-9419-1.

Koschmann, T. (1999). Toward a dialogic theory of learning: Bakhtin's contribution to understanding learning in settings of collaboration. Paper presented at the proceedings of the 1999 conference on computer support for collaborative learning.

Kress, G. (2010). *Multimodality: A social semiotic approach to contemporary communication*. London and New York: Routledge.

Kress, G., & van Leeuwen, T. (2006). *Reading images: The grammar of visual design*. London and New York: Routledge.

Kumpulainen, K., & Lipponen, L. (2010). Productive interaction as agentic participation in dialogic enquiry. In K. Littleton & C. Howe (Eds.), *Educational dialogues: Understanding and promoting productive interaction* (pp. 48–63). London: Routledge.

Lajoie, S. P., Bodnar, S., Hmelo-Silver, C. E., Chen, Y., Zheng, J., Huang, L., & Kazemitabar, M. (2020). Toward quality online problem-based learning. In S. M. Bridges & R. Imafuku (Eds.), *Interactional research into problem-based learning* (pp. 367–390). Indiana: Purdue University Press.

Lemke, J. L. (1998). Metamedia literacy: Transforming meanings and media. In D. Reinking, L. Labbo, M. McKenna, & R. Kiefer (Eds.), *Handbook of literacy and technology: Transformations in a post-typographic world* (pp. 283–301). Hillsdale, NJ: Erlbaum.

Lemke, J. L. (2000). Across the scales of time: Artifacts, activities, and meanings in ecosocial systems. *Mind, Culture, and Activity, 7*(4), 273–290. https://doi.org/10.1207/S15327884MCA0704_03.

Lemke, J. L. (2009). Multimodal genres and transmedia traversals: Social semiotics and the political economy of the sign. *Semiotica, 173*(1–4), 283–297.

Linn, M. C., McElhaney, K. W., Gerard, L., & Matuk, C. (2018). Inquiry learning and opportunities for technology. In F. Fischer, C. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 221–233). NY: Routledge, Taylor & Francis.

Lu, J., Lajoie, S. P., & Wiseman, J. (2010). Scaffolding problem based learning with CSCL tools. *International Journal of Computer-Supported Collaborative Learning, 5*(3), 283–298. https://doi.org/10.1007/s11412-010-9092-6.

Lu, J., Bridges, S. M., & Hmelo-Silver, C. E. (2014). Problem-based learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed., pp. 298–318). Cambridge: CUP.

Ludvigsen, S., Cress, U., Rosé, C. P., Law, N., & Stahl, G. (2018). Developing understanding beyond the given knowledge and new methodologies for analyses in CSCL. *International Journal of Computer- Supported Collaborative Learning, 13*(4), 359–364. https://doi.org/10.1007/s11412-018-9291-0.

Lyle, J. (2003). Stimulated recall: A report on its use in naturalistic research. *British Educational Research Journal, 29*(6), 861–878. https://doi.org/10.1080/0141192032000137349.

Martinez-Maldonado, R., Dimitriadis, Y., Martinez-Monés, A., Kay, J., & Yacef, K. (2013). Capturing and analyzing verbal and physical collaborative learning interactions at an enriched interactive tabletop. *International Journal of Computer-Supported Collaborative Learning, 8*(4), 455–485.

McClelland, M. I., & Sands, R. G. (2001). *Interprofessional and family discourses: Voices, knowledge and practice*. New Jersey: Hampton Press.

Medina, R., & Suthers, D. (2013). Inscriptions becoming representations in representational practices. *The Journal of the Learning Sciences, 22*(1), 33–69. https://doi.org/10.1080/10508406.2012.737390.

Mercer, N., & Howe, C. (2012). Explaining the dialogic processes of teaching and learning: The value and potential of sociocultural theory. *Learning, Culture and Social Interaction, 1*, 12–21.

Mishler, E. (1984). *The discourse of medicine: Dialectics of medical interviews*. New Jersey: Ablex Publishing Corporation.

Mitchell, C. J. (1984). Typicality and the case study. In R. F. Ellen (Ed.), *Ethnographic research: A guide to general conduct* (pp. 213–293). New York: Academic Press.

Moallem, M., Hung, W., & Dabbagh, N. (Eds.). (2019). *Wiley handbook of problem-based learning*. NY: John Wiley & Sons, Inc..

New London Group. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review., 66*(1), 60–93.

Ng, M. L., Bridges, S., Law, S. P., & Whitehill, T. (2014). Designing, implementing and evaluating an online problem-based learning (PBL) environment-a pilot study. *Clinical Linguistics & Phonetics, 28*(1–2), 117–130.

Prosser, M., & Sze, D. (2014). Problem-based learning: Student learning experiences and outcomes. *Clinical Linguistics & Phonetics, 28*(1–2), 131–141.

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Putney, L., Green, J. L., Dixon, C., Duran, R., & Yeager, B. (2000). Consequential progressions: Exploring collective individual development in a bilingual classroom. In C. Lee & P. Smagorinsky (Eds.), *Constructing meaning through collaborative inquiry: Vygotskian perspectives on literacy research* (pp. 86–126). New York: Cambridge University Press.

Quintana, C., Reiser, B. J., Davis, E. A., Krajcik, J., Fretz, E., Duncan, R. G., Kyza, E., Edelson, D., & Soloway, E. (2004). A scaffolding design framework for software to support science inquiry. *The Journal of the Learning Sciences, 13*(3), 337–386.

Raes, A., Schellens, T., & De Wever, B. (2013). Web-based collaborative inquiry to bridge gaps in secondary science education. *The Journal of the Learning Sciences, 23*(3), 316–347. https://doi.org/10.1080/10508406.2013.836656.

Rampton, B. (2017). WP175. Interactional sociolinguistics. Tilburg Papers in Culture Studies. https://www.academia.edu/30796363/WP205_Rampton_2017._Interactional_Sociolinguistics.

Rasi, P. M., & Poikela, S. (2016). A review of video triggers and video production in higher education and continuing education PBL settings. *Interdisciplinary Journal of Problem- Based Learning, 10*(1).

Reilly, C. M., Kang, S. Y., Grotzer, T. A., Joyal, J. A., & Oriol, N. E. (2019). Pedagogical moves and student thinking in technology-mediated medical problem-based learning: Supporting novice-expert shift. *British Journal of Educational Technology, 50*, 2234–2250. https://doi.org/10.1111/bjet.12843.

Roschelle, J., Dimitriadis, Y., & Hoppe, U. (2013). Classroom orchestration: Synthesis. *Computers & Education, 69*, 523–526.

Rummer, R., Schweppe, J., Fürstenberg, A., Scheiter, K., & Zindler, A. (2011). The perceptual basis of the modality effect in multimedia learning. *Journal of Experimental Psychology: Applied, 17*(2), 159–173.

Saussure, F. (1916/1983). Course in general linguistics. (trans. R. Harris). London: Duckworth.

Savin-Baden, M. (2016). The impact of transdisciplinary threshold concepts on student engagement in problem-based learning: A conceptual synthesis. *Interdisciplinary Journal of Problem-Based Learning, 10*(2). https://doi.org/10.7771/1541-5015.1588.

Sheridan, D., Street, B., & Bloome, D. (2000). *Writing ourselves: Literacy practices and the mass observation project*. New Jersey: Hampton Press.

Silverstein, M. (2003). Indexical order and the dialectics of sociolinguistic life. *Language & Communication, 23*(3), 193–229. https://doi.org/10.1016/S0271-5309(03)00013-2.

Smith, A., & Kennett, K. (2017). Multimodal meaning: Discursive dimensions of e-learning. In B. Cope & M. Kalantzis (Eds.), *E-Learning ecologies: Principles for new learning and assessment. (pp. 88-117)*. NY: Routledge: Taylor & Francis.

Stahl, G., Koschmann, T., & Suthers, D. D. (2014). Computer-supported collaborative learning. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed., pp. 479–500). NY: Cambridge University Press.

Steier, R., Kersting, M., & Silseth, K. (2019a). Imagining with improvised representations in CSCL environments. *International Journal of Computer-Supported Collaborative Learning, 14*(1), 109–136.

Steier, R., Kersting, M., & Silseth, K. (2019b). Imagining with improvised representations in CSCL environments. *International Journal of Computer-Supported Collaborative Learning, 14*(1), 109–136.

Stetsenko, A. (2013). The challenge of individuality in cultural-historical activity theory:"Collectividual" dialectics from a transformative activist stance. *Outlines. Critical Practice Studies, 14*(2), 07–28.

Strobel, J., & van Barneveld, A. (2009). When is PBL more effective? A meta-synthesis of meta-analyses comparing PBL to conventional classrooms. Interdisciplinary Journal of Problem-Based Learning, 3(1).

Suárez, A., Specht, M., Prinsen, F., Kalz, M., & Ternier, S. (2018). A review of the types of mobile activities in mobile inquiry-based learning. *Computers & Education, 118*, 38–55.

Suthers, D. D. (2006). Technology affordances for intersubjective meaning making: A research agenda for CSCL. *International Journal of Computer-Supported Collaborative Learning, 1*(3), 315–337.

Tang, K. S., & Danielsson, K. (2017). *Global developments in literacy research for science education*. Switzerland: Springer International Publishing.

Tchounikine, P. (2019). Learners' agency and CSCL technologies: Towards an emancipatory perspective. *International Journal of Computer-Supported Collaborative Learning, 14*, 237–250. https://doi.org/10.1007/s11412-019-09302-5.

Verstegen, D., de Jong, N., van Berlo, J., Camp, A., Könings, K. D., van Merriënboer, J. J. G., & Donkers, J. (2016). How e-learning can support PBL groups: A literature review. In S. Bridges, L. K. Chan, & C. E. Hmelo-Silver (Eds.), *Educational technologies in medical and health sciences education* (pp. 9–34). Switzerland: Springer International Publishing.

Vorvilas, G., Karalis, T., & Ravalis, K. (2010). Applying multimodal discourse analysis to learning objects' user interface. *Contemporary Educational Technology, 1*(3), 255–266 Retrieved from http://dergipark.gov.tr/cet/issue/25721/271416.

Wegerif, R. (2007). *Dialogic education and technology*. New York, NY: Springer.

Wildfeuer, J., & Bateman, J. (2016). Linguistically oriented comics research in German. In N. Cohen (Ed.), *The visual narrative reader* (pp. 19–66). London: Bloomsbury Academic.

Wise, A. F., & Schwarz, B. B. (2017). Visions of CSCL: Eight provocations for the future of the field. *International Journal of Computer-Supported Collaborative Learning, 12*(4), 423–467. https://doi.org/10.1007/s11412-017-9267-5.

Yoon, S. A., & Hmelo-Silver, C. E. (2017). What do learning scientists do? A survey of the ISLS membership. *Journal of the Learning Sciences, 26*(2), 167–183. https://doi.org/10.1080/10508406.2017.1279546.

Zemel, A., & Koschmann, T. (2013). Recalibrating reference within a dual-space interaction environment. *International Journal of Computer-Supported Collaborative Learning, 8*(1), 65–87.