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iTalk–iSee: A participatory visual learning analytical tool for productive peer talk

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Abstract
Productive peer talk moves have a fundamental role in structuring group discussions and promoting peer interactions. However, there is a lack of comprehensive technical support for developing young learners' skills in using productive peer talk moves. To address this, we designed iTalk–iSee, a participatory visual learning analytical tool that supports students' learning and their use of productive peer talk moves in dialogic collaborative problem-solving (DCPS). This paper discusses aspects of the design of iTalk–iSee, including its underlying theoretical framework, visualization, and the learner agency it affords. Informed by the theory of Bakhtinian dialogism, iTalk–iSee maps productive peer talk moves onto learning goals in DCPS. It applies well-established visualization design principles to connect with students, hold and direct their attention, and enhance their understanding. It also follows a three-step (code → visualize → reflect) macro-script to strengthen students' agency in analyzing and interpreting their talk. This paper also discusses the progressive modifications of iTalk–iSee and evaluates its usability in a field study. We present the implications of essential design features of iTalk–iSee and the challenges of using it (relating to, for example, teacher guidance, data collection, transcription, and coding). We also provide suggestions and directions for future research.

Keywords Productive peer talk · Dialogic collaborative problem solving · Talk moves · Computer-supported collaborative learning · Visual learning analytics

Introduction

Productive peer talk is essential for effective collaboration (Chi & Menekse, 2015; Gillies, 2019). Many dedicated efforts have been made by researchers to facilitate productive peer talk during collaboration (e.g., Clark et al., 2003; King, 1997; Roberts & Lyons, 2017; Tegos et al., 2015; Webb et al., 2014). Some of these efforts have focused on teaching students principles or ground rules to structure their discussion (Clark et al., 2003; Littleton & Mercer, 2013; Topping & Trickey, 2013). Others have tried to identify fine-grained talk moves that characterize productive peer talk (e.g., Gillies, 2019). Each productive talk

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move has certain local functions in interactions and provides students with more specific behavioral guidance than macro-level talk principles. Such talk moves have been adapted to various contexts, including intercultural collaboration (Popov et al., 2019), collaborative knowledge building (Avcı, 2020), and collaborative problem solving (Byun et al., 2014).

Dialogue is central to research on computer-supported collaborative learning (Baker et al., 2021). Researchers have attempted to develop visual learning analytical tools to facilitate productive peer interaction (Hu & Chen, 2021; Martinez-Maldonado et al., 2021). However, these tools mainly focus on the online context and seldom consider learning theories and visualization design principles. Additionally, most are simply mirroring tools that provide few advanced interpretations for users, such as cueing desired or important events or suggesting strategies or remedial actions.

This paper describes our efforts to facilitate productive peer talk during collaboration by developing a participatory visual analytical tool called iTalk–iSee. Our study examines face-to-face dialogic collaborative problem-solving (DCPS) by primary school students. Informed by research on the limitations of current visual learning analytical tools (Hu & Chen, 2021; Martinez-Maldonado et al., 2021; Vieira et al., 2018), iTalk–iSee is based on both learning theories and visualization design principles and provides advanced affordances for students. This paper describes the design of iTalk–iSee regarding its theoretical framework, visualization, and the learner agency it affords. It also discusses the progressive modifications of iTalk–iSee and examines its usability in a field study.

Tool design

iTalk–iSee[1] is a participatory visual learning analytical tool designed to improve students' DCPS competencies by helping them learn how to use specific productive peer talk tools and enabling them to experience the benefits of authentic dialogue. The "iTalk" part of the name indicates the tool's focus on promoting and supporting a culture of dialogue, while the meaning of "iSee" is twofold: the tool helps learners visualize collaborative discourse, which allows them to intuitively *see* their talk; it also helps learners *understand* their collaboration performance and determine how to improve their discussion by *seeing* their talk. In this section, we introduce the three essential design elements of iTalk–iSee: its theoretical framework, its visualization capabilities, and the learner agency it affords.

Theoretical framework: conceptualizing talk moves as talk tools

There is a growing awareness among researchers regarding how specific learning theories can guide the development of learning tools (Hillaire et al., 2016; Martinez-Maldonado et al., 2021; Shaffer & Ruis, 2017; Wise & Schaffer, 2015). The development of iTalk–iSee is rooted in Bakhtinian dialogism (Bakhtin, 1981). Dialogism is a prominent theoretical framework for understanding computer-supported collaborative learning (Koschmann & Schwarz, 2021; Trausan-Matu et al., 2021). iTalk–iSee conceptualizes empirically grounded productive talk moves as useful talk tools for primary school students in various contexts and provides advanced affordances to facilitate the use of these tools in DCPS.

[1] Check http://demo.italkisee.com/ for the demo of iTalk–iSee.

The term "tool" usually refers to "a device or implement, especially one held in the hand, used to carry out a particular function" (Lexico, n.d.). Tools "make sense" when they are designed to solve problems or fulfill specific purposes. Productive peer talk moves are typically directed toward local goals in a conversation. To conceptualize them as talk *tools* facilitating DCPS, it is necessary to identify the essential features of effective DCPS and structure talk moves to provide these features. This is in line with collaboration analytics, which emphasizes the use of well-established educational theories to map low-level observable data onto higher-order group constructs to generate actionable group insights (Martinez-Maldonado et al., 2021). In the following section, we define DCPS and discuss four essential features of effective DCPS. We then discuss how productive peer talk moves can be conceptualized as talk tools to support these features.

Defining DCPS

Bakhtin (1999) argued that there is no fixed and final knowledge or truth but that truth emerges from unlimited dialogue involving "*a plurality of [opaque, non-transparent] consciousnesses*, with equal rights and each with its own world, [that] combine but are not merged in the unity of the event" (p. 6, italics in original). In collaborative problem-solving, "two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution" (OECD, 2013, p. 6). According to Friend and Cook (1992, p. 5), "Interpersonal collaboration is a style of direct interaction between at least two co-equal parties voluntarily engaged in shared decision making as they work toward a common goal." Therefore, collaborative interaction involves the interanimation of two or more independent and co-equal consciousnesses, echoing Bakhtin's notion of dialogic interaction.

Referring to Bakhtin's dialogic framework (1999), we define *dialogic collaborative problem-solving* as a complex dynamic process in which two or more consciousnesses, with equal rights and each with its own world, combine but are not merged in the unity of solving a shared problem. This definition acknowledges that dialogue adds to collaborative problem-solving on at least two levels. First, DCPS emphasizes the role of dialogue in collaborative problem-solving. This is consistent with other theoretical perspectives that emphasize the role of language in thinking (Piaget, 1932; Vygotsky, 1978). Second, DCPS emphasizes problem-solving through dialogic interaction in which collaborators treat each other as equals and engage in internally persuasive rather than authoritative discourse (Bakhtin, 1981; Wegerif, 2020).

Features of effective DCPS

Effective DCPS requires genuine dialogue that is rooted in Bakhtinian dialogism (Bakhtin, 1929/1984). An essential feature of such dialogue is the presence of equality and respect among voices (Bakhtin, 1929/1984). According to Bakhtin, those who are unequal are not likely to engage in dialogic interactions or generate knowledge or truth. Therefore, genuine dialogue is typically impossible for groups where there is severe social loafing (Simms & Nichols, 2014) or marginalization. Research on collaborative problem-solving has also emphasized the equality of individual participation (Asterhan & Schwarz, 2009; Dillenbourg et al., 2016). Verbal inequity may lead to information loss, dominance by a majority, and limitations of a team's potential to solve various problems (Borge & Carroll, 2014; Woolley et al., 2010). When students do not treat each other as equals, destructive discourse may occur whereby teammates devalue, ignore, or exclude the ideas of others rather than interacting respectfully and responsively. Such destructive discourse tends to result in a lack of psychological safety and an unsatisfactory collaborative experience, which inhibits group problem-solving and learning (Borge et al., 2018; Edmondson, 1999; Strauß & Rummel, 2021). Rudeness in social interactions can also hinder group progress and reduce the quality of group solutions (Chiu & Khoo, 2003), while social conflict may hamper the knowledge-construction process (Xie et al., 2013). Therefore, equality and respect are essential for effective DCPS.

Genuine dialogue, according to Bakhtinian dialogism, also requires individuals to be open-minded (Bakhtin, 1929/1984); individuals should interact in an internally persuasive rather than authoritative manner and allow others to change their minds (Bakhtin, 1981). Students are unlikely to engage in genuine dialogue if someone refuses to listen to or accept the views of others without careful consideration. Research on collaborative problem-solving has also emphasized the significance of interdependence among group members, which is essential to help them build and maintain a shared understanding (Barron, 2003; Johnson & Johnson, 1989; OECD, 2017; Swiecki, 2021). Such interdependence echoes the requirement for open-mindedness in genuine dialogue and emphasizes the need for authentic engagement with others' ideas in collaborative work.

In addition to genuine dialogue, establishing a joint solution is an important goal of DCPS. In this context, equal consciousnesses combine but are not merged to solve a shared problem. Therefore, effective DCPS is also characterized by convergence on a joint solution. Such convergence does not involve the increasing similarity of individual knowledge that occurs when cognitive conflicts are resolved (Weinberger et al., 2007) nor does it require agreement to be achieved. Instead, such convergence occurs when all individuals make efforts to reach an optimum joint solution through dynamic task regulation (Baker et al., 2020). Research on effective collaborative problem-solving has also emphasized the essential role of effort convergence (Hmelo-Silver et al., 2009). Success is unlikely if there is no coordination among group members concerning effort and participation (Barron, 2003). Therefore, effort convergence on a joint solution is essential for effective DCPS.

Based on the above, we conclude that there are three essential goals of DCPS, which reflect the four essential talk virtues of equality, respect, open-mindedness, and convergence (see Fig. 1): goal 1 (equality and respect) relates to the social aspect of DCPS, while goals 2 (open-mindedness) and 3 (convergence) relate to the task aspect. Goal 2 is divided into two parts that correspond to the two parties in a dialogue, which indicates the open-mindedness of both parties in dialogic interactions.

Mapping talk moves onto goals in DCPS

Studies have identified several productive peer talk moves that characterize productive peer interactions (e.g., Gillies, 2019; King, 1997; Noroozi et al., 2013; Webb et al., 2014). Based on a synthesis of studies on the efficacy of productive peer talk moves (Hu & Chen, 2022), we extracted a list of 24 frequently validated productive peer talk moves (Table 1 in Online Resource 2). We further conceptualized them as 18 talk tools to fulfill the three goals of DCPS (see Fig. 2).

Research has shown that people learn more deeply when words are spoken in a conversational rather than a formal style (Mayer, 2014b). A first- or second-person perspective can be adopted to achieve a more conversational style of language. Therefore, we structured the talk tools into three categories according to the corresponding personal

Fig. 1 The three goals of DCPS

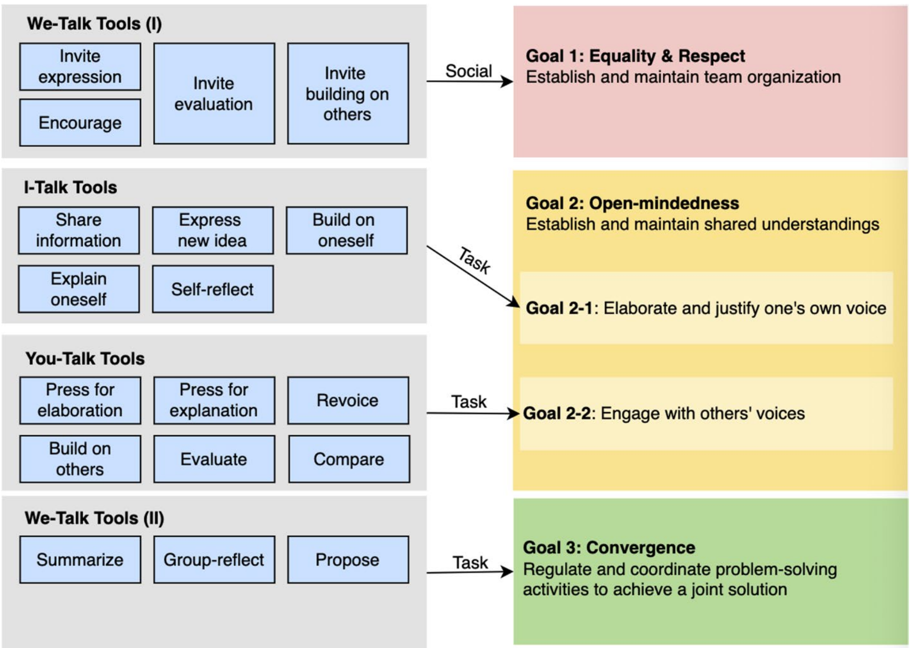

Fig. 2 Mapping talk moves to goals in DCPS

pronouns (“I-Talk,” “You-Talk,” and “We-Talk”) to enhance the information retention and understanding of young learners. I-Talk tools were used to persuade others by elaborating and justifying one’s viewpoints, You-Talk tools were used to interact with others by engaging with their viewpoints, and We-Talk tools were used for team organization and consensus-building.

Visualization design

Learning theories and visualization designs must be further integrated into the development of educational visual learning analytical tools (Hu & Chen, 2021; Vieira et al., 2018). Grounded in DCPS, iTalk–iSee follows the eight psychological principles of effective graphic design proposed by Kosslyn (2006) to visualize collaborative discussion processes for young learners (see Table 1). These principles are not hard-and-fast rules but rather useful guidelines based on the real data and questions behind the graphics. Therefore, we also considered other suitable visualization design practices and principles for the multimedia learning materials when designing the visualizations in iTalk–iSee.

A good visual design should balance both functional and aesthetic aspects (Simoff et al., 2008). It should be visually inviting and its message (delivered as patterns, trends, or comparisons) should be comprehended easily and quickly by learners (Kosslyn, 2006). Therefore, it is essential to choose an appropriate visual format. Bar graphs can be used for comparison, line graphs can show trends, pie charts can illustrate parts of a whole, and scatterplots can provide an overview of the relationship between two variables (Kosslyn, 2006). Additional decorative components should not obscure the message of the graph (Kosslyn, 2006). Although studies have shown that complementing text with graphs can promote learning and problem-solving (Hu et al., 2021; Mayer, 2014a), graphs are not always superior to tables or text; they are suitable for illustrating relative amounts in comparisons, trends, or value spreads but not for conveying absolute values. It is thus suggested that numbers be added in critical places when graphs are used to convey both relationships and absolute values (Kosslyn, 2006). The effectiveness of visual representations also depends on individual expertise and the difficulty of the task. For example, in science learning, younger children with less prior knowledge benefit more from visual representations than older children with more prior knowledge (Leslie et al., 2012). Some studies have found that adding visual representations is also beneficial for experts, particularly when they engage in graphics-related tasks, very low-order remembering tasks, and high-order problem-solving (Chiu & Mok, 2017; Nievelstein et al., 2013). For example, Chiu and Mok (2017) found that visual aids could help advanced learners to develop analytical skills in less structured tasks. Therefore, a good visual design should consider its desired functions and contextual factors. It should aim to connect with audience members, direct their attention, and promote understanding and information retention (Kosslyn, 2006). The design of iTalk–iSee is discussed below concerning these three aims.

Connecting with primary school students

iTalk–iSee is aimed at young learners. It was originally designed for Chinese fourth-grade primary school students in the context of Jiangsu province. Therefore, relevant characteristics of this population were considered. According to Kosslyn (2006), effective visual communication should present an appropriate amount of information relevant to the audience, who should have sufficient prior knowledge to read and understand the visual presentations. Effective graphic design should be tailored to the visual literacy of the audience (Galesic & Garcia-Retamero, 2011; Ryan, 2016). Therefore, it was essential to consider primary school students' competencies in reading and understanding visual representations

Table 1 Graph design principles (Kosslyn, 2006)

Aim	Principle	Explanation
Connect with audience	1. Relevance	Communication is most effective when neither too much nor too little information is presented
	2. Appropriate knowledge	Communication requires prior knowledge of relevant concepts, jargon, and symbols
Direct and hold attention	3. Salience	Attention is drawn to large perceptible differences
	4. Discriminability	Two properties must differ by a large enough proportion to be distinguishable
Promote understanding	5. Perceptual organization	People automatically group elements into units, which they then attend to and remember
	6. Compatibility	A message is easiest to understand if its form is compatible with its meaning
	7. Informative changes	People expect changes in properties to carry information
	8. Capacity limitations	People have a limited capacity to retain and process information and will not understand a message if too much information must be retained or processed

when undertaking the graphic design for iTalk–iSee. However, although illustrations are common in children's textbooks, few studies have focused on the visual literacy of K–12 audiences (Thompson & Beene, 2020). Although there has been no systematic analysis of visual representations in textbooks for Chinese pupils, some studies have been conducted on their international counterparts. For example, Dewolf et al. (2015) analyzed four representative Flemish mathematical textbooks and found that approximately 75% of written problems were illustrated, with a slightly decreasing percentage with increasing elementary grade. Alper et al. (2017) conducted a systematic analysis of existing data visualizations in mathematics textbooks for grades K to 4 in the US and found that the six most common visualization types were structured pictographs, tables, free-form pictographs, pictographs, fraction diagrams, and bar charts. They investigated the degree of abstraction of these visualizations and found that it increased from grades K to 4. Cross-national comparative studies have indicated that generative and symbolic representations are more valued by students and teachers in China than in the US, who place more value on concrete verbal or visual representations (Cai, 2000; Silver et al., 1995). This may indicate that Chinese students can understand abstract visualizations more easily than their American peers. Chinese fourth-graders in Jiangsu province learn about statistical tables and bar charts in their first semester (Ministry of Education, 2013a) and spatial notations with the aid of coordinate axes in their second semester (Ministry of Education, 2013b) (see Fig. 1 in Online Resource 1). Additionally, they are exposed to similar visualizations in their textbooks before the fourth grade. Therefore, they can be expected to be familiar with these types of representations.

iTalk–iSee makes use of illustrations that should be familiar to Chinese fourth-graders, including tables, bar graphs, and spatial notation (see Fig. 2 in Online Resource 1), to help visualize collaborative discourse for these young learners. To visualize spatial notation, iTalk–iSee uses bubble plots, a form of temporal visualization commonly used to illustrate features of collaborative discourse (Hu & Chen, 2021). Line graph and network visualizations are also used to fulfill the functions of iTalk–iSee. A line graph is a common form of visual representation and is suitable for presenting temporal information. Line graphs are not complicated to learn and thus do not consume a great deal of pupils' cognitive resources. Therefore, iTalk–iSee uses line graphs to illustrate changes in particular discourse features in the process of a group discussion. However, some guidance on how to interpret the graphs may be necessary. iTalk–iSee also includes a network format as this offers a powerful visual tool to display interdependence among group members (Gašević et al., 2018; González-Howard, 2019; Hu & Chen, 2021). However, compared with line graphs, networks may be less familiar to young learners. Pre-training on how to read and understand networks is essential to equip students with sufficient prior knowledge before they can process the complicated information presented (Mayer & Pilegard, 2014).

Engaging primary school students

According to Kosslyn (2006), another aim of an effective graphic is to direct and hold the audience's attention by highlighting large perceptible differences. iTalk–iSee addresses this aim by broadly focusing on how to attract and engage young learners when they interact with visual representations.

One way to engage users is through visual embellishments, which are more likely to be remembered than plain graphics (Bateman et al., 2010; Borgo et al., 2012). Such embellishments may also make visualizations emotionally arousing and thus more memorable (Mather & Nesmith, 2008). From a minimalist perspective, visual embellishments have been viewed as "chart junk" because they are not essential to understanding data (Tufte, 1983). Minimalists have suggested reducing visual embellishments as much as possible because redundant elements might obstruct the interpretation of essential data and reduce processing speeds. The cognitive theory of multimedia learning also recommends ruthlessly removing any extraneous material so that only essential information is highlighted (Mayer & Fiorella, 2014). However, some studies have found that visual embellishments do not necessarily affect interpretations and may even enhance long-term recall, although they necessitate a longer processing time (Bateman et al., 2010; Borgo et al., 2012). Studies of how decorative pictures affect learning and problem-solving have yielded similar results. Lenzner et al. (2013) reported that decorative pictures drew little attention but helped induce a better mood and more alertness and calmness during learning. These effects were more pronounced for novice learners. Decorative pictures have also been shown to lower individuals' perceptions of task difficulty (Schneider et al., 2016).

These studies have cast doubt on the rule of thumb that "less is more" which requires extraneous information to be minimized (Mayer & Fiorella, 2014) and encourages the pursuit of the lowest data-to-ink ratio in visualization design (Tufte, 1983). Some scholars have proposed that the effect of this rule of thumb is modulated by the learner's cognitive capacity (Wiley et al., 2014), the total cognitive load of the task (Park et al., 2011), and the attractiveness of the extraneous material (Lenzner et al., 2013; Schneider et al., 2016). When learners have additional cognitive capacity remaining after the essential information has been processed, visual embellishments tend to generate a positive affective experience and strengthen information retention without harming the essential interpretation of the data. As young pupils are easily distracted when learning, it is vital to attract and hold their attention to arouse and maintain their motivation. Therefore, iTalk–iSee includes several embellishments as visual metaphors and creates a positive emotional tone by using bright colors for visual representations and the overall interface.

Visual metaphors are powerful learning tools that help to simplify complex problems and promote conceptual understanding (Schwartz, 2020). They have been integrated into visual learning analytical tools to facilitate comprehension (Liu et al., 2012; Xiong & Donath, 1999). A typical visual metaphor is a familiar or intuitive image that shares some essential qualities with the target concept. iTalk–iSee adopts four major visual metaphors to represent the talk virtues in dialogic collaboration and three categories of talk tools (see Fig. 3 in Online Resource 1). The distribution of talk turns is represented by a windmill metaphor. A functional windmill must have balanced sails. Therefore, the familiar windmill metaphor is used to intuitively indicate to learners the desired state of a balanced distribution of individual talk turns. A five-pointed star is used as a metaphor for the five I-Talk tools, indicating the central and initiative role of *I* in peer interactions. The lemon-slice metaphor indicates the challenge of understanding others via the image of getting through a thick lemon peel and enduring its sour flavor. The rainbow flower is a metaphor for the seven We-Talk tools; it has seven petals of different colors and becomes beautiful when in full bloom, indicating the desired state of the full expression of different voices and coherence among group members.

All four visual metaphors are variations of bar charts, with each bar representing the cumulative frequency of a talk feature. Unique visualizations such as these are more likely to be remembered than traditional and common visualizations (Borkin et al., 2013). Allowing users to create their own visual elements and personalize the visual design can also make them feel more engaged in the learning process. Therefore, iTalk–iSee allows students to create their own avatars (see Fig. 4 in Online Resource 1) and embeds these avatars into the visualizations to encourage students to relate more strongly to the visuals (e.g., Fig. 3a in Online Resource 1).

Promote understanding

Kosslyn (2006) suggested that effective graphic design should aim to promote understanding. He noted the importance of several fine-grained principles concerning perceptual organization, compatibility between form and content, informative changes, and limited cognitive capacity. In addition to following these principles in visualization design, iTalk–iSee adopts multiple visual representations and reference frames to facilitate and scaffold users' understanding.

Multiple representations can enhance learning (Ainsworth, 2014). Three main functions of multiple representations have been identified: complementary, constraining, and constructing (Ainsworth, 2006). Multiple representations that exemplify unique aspects of learning objectives can provide complementary information. A familiar representation may facilitate students' understanding of a novel or complex representation. Multiple related representations can facilitate students' knowledge construction whereby they can integrate information distributed across multiple representations. In complex domains, multiple visual representations can provide students with complementary information, unlike an individual visual representation (Rau, 2013; Rau et al., 2015). However, such added value only materializes when students can build connections among multiple representations; otherwise, their learning might be jeopardized (Rau, 2017). Most students do not spontaneously integrate multiple representations, which requires representational competence (Schwonke et al., 2009); therefore, some instructional support is necessary to foster flexible knowledge acquisition from multiple visual representations (Rau, 2017).

To enhance students' understanding of talk virtues, iTalk–iSee provides multiple complementary visual representations to explore students' performances from various perspectives. For example, students can access three different visualizations of their usage of I-Talk tools in DCPS (see Fig. 5 in Online Resource 1). The five-pointed star indicates whether they have reached the standard established for each tool. The bar chart shows students their usage rate for each tool and the average usage rate of the whole class signified by short red lines. The bubble plot presents detailed temporal information on the individual usage of I-Talk tools throughout the collaboration process. These three visualizations focus on various aspects of the students' use of I-Talk tools and are deeply connected and cross-validated. Together, they provide students with a comprehensive understanding of their performance concerning elaborating and justifying their own voices. However, it may be necessary to provide students with explicit guidance on the complementary functions of these visualizations to fully achieve their intended benefits.

Visual representations for analyzing collaborative discourse are suggested to provide advanced affordances such as alerts about critical events or advice regarding remedial solutions, which may generate actionable group insights (Hu & Chen, 2021; Martinez-Maldonado et al., 2021). It is also recommended that learning analytics interventions for students add reference frames to help the students evaluate their analytics (Wise, 2014). Thus, iTalk–iSee provides students with two types of reference frames to help them understand the visualizations and reflect on their talk quality. One type serves as assessment criteria and is used for analyzing the equality and usage of the talk tools. iTalk–iSee quantifies participation inequality as the standard deviation of individual participation rates (Kapur et al., 2008) and categorizes participation inequality into five levels, from strongly unequal to strongly equal. Each windmill of talk turns is cued with the corresponding equality level to help students reflect on their collaboration process. For the other visual metaphors for talk tool usage (see Fig. 3 in Online Resource 1), the complete growth state for each talk tool corresponds to the desired usage rate set by the teacher to assess group performance. The other type of reference frame relates to peers' relative performances. This is provided for the analysis of talk tool usage. For example, in the I-Talk usage rate bar chart, the average usage rate of the whole class is available to students to position and reflect on their group performance (see Fig. 5 in Online Resource 1). It is also possible to select various group members to show individual usages of I-Talk tools. With the aid of these relative reference frames, students can make sense of their group's performance by positioning the group relative to the whole class and of their individual performance by conducting within-group comparisons.

Learner agency

When using learning analytics tools, students often face challenges associated with the need to identify teachers' pedagogical intentions and the expectation that they generate productive engagement patterns (Echeverria et al., 2018; Wise, 2014). Wise (2014) suggested that effective learning analytics intervention designs should facilitate student agency; that is, they should support rather than detract from students' development and use of self-regulatory skills. From the perspective of visual analytics, it is assumed that analytics alone cannot provide a single best solution due to the complexity of real-world problems (Hu & Chen, 2021; Keim et al., 2009). Instead, it is better to integrate human experience, knowledge, and creativity and incorporate users' agency into the processes of analysis and interpretation. According to cognitive load theory, the robust generation effect means that people learn better when they actively extract or induce learning content rather than passively receiving it (Bertsch et al., 2007). iTalk–iSee is, therefore, participatory. It does not provide students with ready-to-use analytics results but engages them in the analytical process. It provides interactive visual interfaces to help students analyze their collaborative discourse around the three goals of DCPS. It primarily supports three aspects of analysis: participation equality (i.e., "Did we talk equally?"), talk tool usage (i.e., "Did I make myself understood?", "Did I understand others?", "Did I talk for the group?"), and longitudinal changes (i.e., "Did we make progress?"). iTalk–iSee provides students with the three-step macro-script *code → visualize → reflect* to scaffold their coding of the group talk (*I-Talk*) and allow them to visualize the coding results (*I-See*, intuitively seeing the talk) and reflect on their group talk with the aid of visualizations (*I-See*, understanding how they have performed and how to improve).

In the coding step, iTalk–iSee provides students with multiple synchronized panels to ease and facilitate coding. For example, in the analysis of I-Talk tools to answer the question "Did I make myself understood?", iTalk–iSee provides students with a video of their group talk (panel A) and a synchronized transcribed discourse (panel B) (see Fig. 6 in Online Resource 1). Students can easily review the video and transcripts turn by turn and code them by selecting appropriate I-Talk tools from panel C. They can also adjust their coding by comparing it with an example provided by the teacher. This coding step does not evaluate the accuracy of student coding but guides students to illuminate their discussion process, familiarize them with the talk analysis procedure, deepen their understandings of the talk tools, and increase their awareness of tool usage. iTalk–iSee allowed teachers to select problem-solving talk segments with different lengths for their students to code. Due to time limitations, we only assigned students a selected segment that lasted for approximately 10 turns in our field study. Although their coding did not affect the follow-up visualizations, which were produced based on the coding of professional coders, students experienced the process of creating the visualizations through this coding step.

Upon completing the coding step, students can access the visualizations (e.g., Figs. 2, 3, and 5 in Online Resource 1). They are then guided to reflect on the problems posed by teachers by referring to the visualizations and structured questions. For example, when considering the question "Did I make myself understood?", students are prompted to identify which I-Talk tools met the usage standards and which were used least and discuss why they seldom used certain tools and how to improve their usage (see Fig. 1 in Online Resource 2). By involving students in the coding process that is implicit in the visualizations and advanced feedback, iTalk–iSee helps students understand the various talk virtues and tools, how to analyze and evaluate their group talk, and how the visualizations are produced. This participatory approach strengthens students' agency in reviewing, analyzing, and reflecting on their group performance. It avoids merely communicating ready-made interpretations and evaluations, which may be easily affected by students' lack of awareness of the intended design and their ideas about expected behavior.

iTalk–iSee also uses a gamified evaluation system to strengthen students' agency and motivation to learn and reflect on the application of talk virtues and talk tools (Strmecki et al., 2015). The primary element of the gamified evaluation system is badge collection. Many pupils in Jiangsu province enjoy playing card collection games in their spare time. They collect attractive cards, aiming to acquire complete sets. Their desire to collect the cards is usually stronger when they compete with their peers. Therefore, iTalk–iSee includes 22 attractive badges for the four talk virtues (equality, respect, open-mindedness, and convergence) and 18 talk tools (e.g., Fig. 7 in Online Resource 1). Groups receive badges for each DCPS task if their performance meets relevant standards. For example, in the windmill of talk turns, if participation equality achieves the level of *equal* or *strongly equal*, students will receive the badge for equality. iTalk–iSee presents and updates collected badges after each task. This process also enables students to track the performance of other groups.

Tool evaluation and improvement

To evaluate and improve the design of iTalk–iSee, we applied it in a design-based project to teach students how to talk productively in collaborative problem-solving. The project was implemented as an independent elective course entitled "Mathematics Dialogue and Thinking." iTalk–iSee was an essential tool in the course to facilitate students' analyses of and reflections on their group talk. In the following sections, we report how iTalk–iSee was progressively modified in the field and how participants perceived their experience with iTalk–iSee. We also examine the usability of iTalk–iSee by describing one group's interaction process with iTalk–iSee.

Participants

The project's participants were recruited from one low-ranking primary school in a third-tier city in China. The school had six large and academically comparable classes of fourth-graders (approximately 60 students per class). One of the classes ($N=59$) was randomly chosen to test the iTalk–iSee-supported course. Written consent forms were collected from the principal, the mathematics teacher of the class, and the children's guardians. The participants were aged between 9 and 10 years and 59% of them were male. They were grouped into 19 triads and one dyad, with a balance of academic statuses.

Pseudonyms are used to protect the children's identities. The selected group (number 18) was composed of three students named Xing (male), Wang (female), and Pan (female). Xing's prior mathematics grade was the highest among the three, Wang's was the middle, and Pan's was the lowest. The prior problem-solving performance of this group was in the upper level for the class. However, they struggled with getting the equality badge as Xing tended to dominate the group.

Course design and setting

This course comprised two lessons per week in a classroom equipped with a video recording system. The first author was the teacher of this course; the second author was the teaching assistant. There were eight learning lessons, conducted on Fridays, interspersed with eight practice lessons, conducted on Tuesdays, with four review lessons interspersed throughout the semester. In a learning lesson, students learned new talk virtues/tools and used iTalk–iSee to analyze their usage of these talk virtues/tools in their previous collaborative task. They then applied the newly learned talk virtues/tools to a new task in a practice lesson. A review lesson took place after two or three cycles of learning and practice lessons and focused on systematically reviewing the learned content and discussing advanced topics such as longitudinal analysis or the combination of various talk tools.

The selected talk analysis task took place in the learning lesson on I-Talk tools. The students followed the three steps of iTalk–iSee (code → visualize → reflect) to analyze their usage of I-Talk tools in solving a mathematical word problem. The word problem told students the prices of various types of tickets to a museum (child ticket, adult ticket, family ticket, and team ticket) and required them to design the most economical ticket plan for three adults and 14 children (see Fig. 2 in Online Resource 2).

Instruments, data collection, and analysis

We recorded classroom videos of each session. All the groups were separately recorded solving the practice problems and analyzing their group talk using iTalk–iSee. All group videos were transcribed, and three trained coders coded the problem-solving transcripts by labeling 18 talk tools (see Fig. 2). Fuzzy kappa, a modified version of Cohen's kappa that allows each unit of analysis to be assigned multiple codes (Kirilenko & Stepchenkova, 2016), was used to measure the inter-coder agreement on the coding of the talk tools. The indicators for three pairs of coders were all satisfactory (fuzzy kappa values >0.60).

To evaluate and improve the design of iTalk–iSee, we interviewed representative groups at the middle and end of the course. We also invited the participants to fill out usability scales and complete a final survey at the end of the course. The system usability scale (Bangor et al., 2008) is a valuable and robust tool to assess the quality of user interfaces through ten simple and quick questions and one additional adjective rating (see Table 2 in Online Resource 2). We also included the widely used net promoter score (Reichheld, 2003) to measure the students' attitudes toward iTalk–iSee by asking them to answer the question "How likely are you to recommend iTalk–iSee to a friend or classmate?" on a scale of 0–10. This score categorized users into three categories: promoters (choosing 9–10), passives (choosing 7–8), and

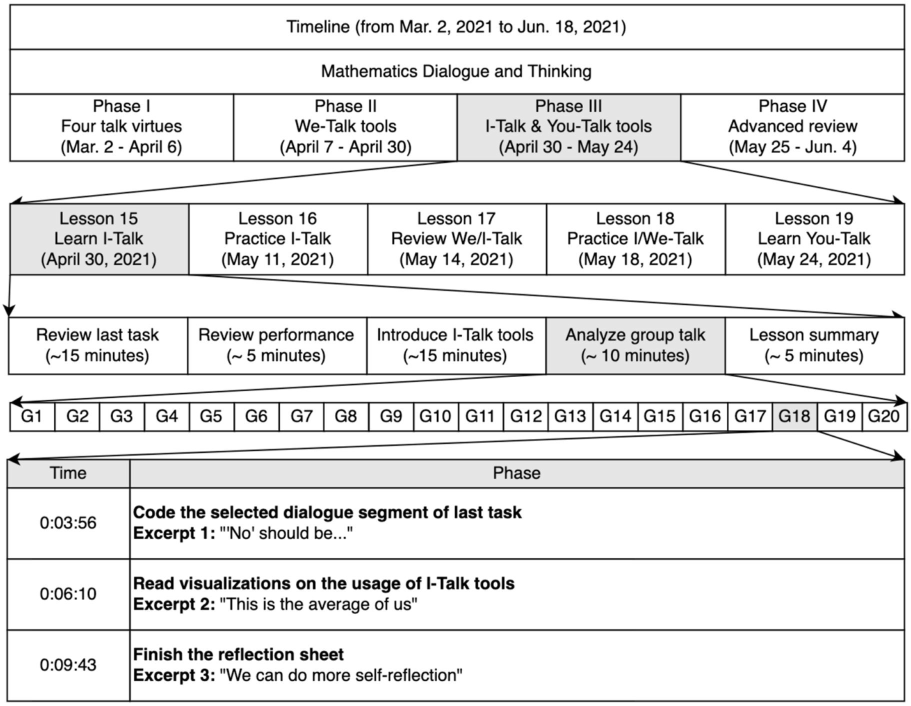

Fig. 3 Event Map: Interactions with iTalk–iSee

detractors (choosing 0–6), and calculated the percentage of promoters relative to detractors. The final survey investigated students' perceived difficulty, helpfulness, and attractiveness of the three-step affordances of iTalk–iSee.

In addition to analyzing students' subjective user experience, we adopted interactional ethnography as a logic-of-inquiry to examine how students interacted with the three-step affordances of iTalk–iSee in the field. Interactional ethnography helps researchers identify rich points (Agar, 2006) that interest and confuse researchers and further serve as anchors for decomposing the complexity of observed phenomena. An interactional ethnography logic-of-analysis selects telling cases to unfold the non-linear interaction dynamics and constructs a graphic representation of events, called event mapping, to suit the focused analysis of rich points (Bridges et al., 2020; Green & Bridges, 2018).

We selected the talk analysis task of the I-Talk tools for group 18 as a telling case to discuss how students interact with the three-step affordances of iTalk–iSee. This group did not perform best in this task but they produced representative interactions with iTalk–iSee. We identified three rich points of collaboration at each of the three steps of iTalk–iSee. The event map in Fig. 3 anchors the focused task in the whole course and highlights the chronological relationships between key events of this group's interaction with iTalk–iSee.

Table 2 Major improvements of iTalk–iSee during application

Time	Improved elements	Data source
2021/3/5–2021/3/12	Data collection and pre-processing module	Test through warm-up collaborative task
2021/3/22–2021/3/26	Reflection sheet User interface	Test through warm-up talk analysis task
2021/4/28–2021/5/11	1. The workload and logic of coding tasks 2. The talk network, bubble plot, and response rate bar chart designs 3. The user interface design	Mid-term preliminary analysis and feedback from group interviews

Results

Progressive modifications in the field

iTalk–iSee went through three major rounds of improvement during the course (see Table 2). The first refinement mainly focused on the complementary data collection and pre-processing module of iTalk–iSee. This module aimed to collect high-quality group audio for transcribing and follow-up professional coding. The noisy background of the classroom made it quite challenging to collect satisfactory data for automatic transcribing. We originally assigned each student a bone conduction microphone to capture individual talk separately. This plan turned out to be impractical during a warm-up task in which the students became familiar with their new group members. It was quite time-consuming to ensure that all of the approximately 60 students wore the bone conduction microphone correctly and held it throughout the task. Therefore, we gave up the plan of automatic transcribing and designed a simpler and less intrusive data collection method (see Fig. 4). This method needed two mobile phones, one for audio recording and one for video recording, and one fish-eye lens to widen the camera angle. We also hired transcribers to ensure the correct and timely transcription of the audio–visual data. Meanwhile, we tested the stability and the uploading speed of the module through this warm-up session and improved the module performance based on detected technical issues.

Another refinement of iTalk–iSee happened after the students' first usage of iTalk–iSee in a practice talk analysis task. In this task, we guided the students to analyze a sample talk to familiarize them with the major three-step affordances of iTalk–iSee (i.e., code → visualize → reflect). This practice revealed problems with the design of the reflection sheet. In the original version of the reflection sheet, we provided the students with only open-ended questions and prompted them to use appropriate visualizations to answer. However, several groups approached us for guidance on how to answer these open-ended questions. Most of the groups left the reflection sheet blank. We talked to some of the students and found that they understood the reflection questions but had difficulties in expressing themselves clearly. Therefore, we changed some of the open-ended questions to multiple-choice questions to facilitate the thinking and discussion of the primary school students.

A systematic refinement of iTalk–iSee occurred at mid-term when students had used iTalk–iSee for five talk analysis tasks. We reviewed how the students interacted with iTalk–iSee and interviewed three representative groups about their user experience and any

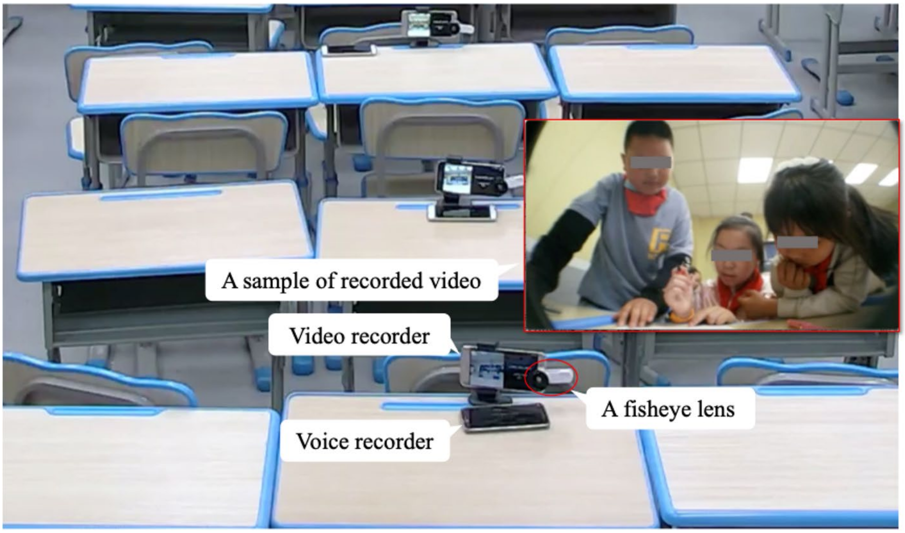

Fig. 4 Group video recording

suggestions they had. This led to a set of changes in the design of iTalk–iSee. Regarding coding, we found that some groups directly copied the reference codes or even skipped the coding to see the visualizations. The interviewed students reported that sometimes they were impatient with the step-by-step coding, and most were eager to see the visualizations. We therefore stressed the significance of the coding step in class and made coding a compulsory step that had to be accomplished before getting to the visualizations. Additionally, we made a change so that the students could not check the reference codes until they had submitted their own codes. We also decreased the coding workload from approximately 15 turns to 10 turns.

Regarding the visualizations, the interviewed students thought that the social network was complex, that some of the small bubbles in the bubble plot could not be seen, and that it was difficult to understand the response rate. We therefore simplified the social network by removing the group node (not showing the talk addressing to the whole group), refined the bubble size formula to ensure that all of the bubbles were visible, changed the response rate format from a decimal to a percentage, and elaborated on the meaning of the response rate using a concrete example. There were no further changes concerning the reflection sheet. Meanwhile, we made some minor changes to the user interface according to student feedback, such as changing the place of the task clock and adding the names of some coordinate axes.

User experience

The overall score of the system usability scale was 71.8 out of 100, indicating that iTalk–iSee was at least passable (Bangor et al., 2008). Although the overall score was not high, the students gave iTalk–iSee high ratings on the adjectival rating scale—53% of the students rated iTalk–iSee as an excellent product, 22% rated it very good, and 22% rated it OK.

As measured by the net promoter score, 54% of our participants were promoters, 14% were passives, and 32% were detractors. The net promoter score was 75 on a range of − 100 to 100, which indicates a strong recommendation tendency among our participants.

According to the post-course survey, approximately 76% of the students thought that the coding task was simple. Some of the students reported that their group always made mistakes in coding, which required group discussions, and some pointed out that their group did not know what to do when they had no idea what the appropriate codes were. Almost all of the students thought the coding task was interesting (97%) and helpful for improving group talk (95%).

The current 13 different types of visualizations in iTalk–iSee were favorites of most of the students. Each type was liked by 87% of the students on average. Specifically, the windmill, the lemon slice, the dynamic line graph, the response rate bar chart, and the five-pointed star were liked by more than 90% of the students because they were simple, clear, and pretty. Meanwhile, approximately 15%–20% of the students disliked the social network graph, the usage rate bar chart, and the tool usage bubble plot, because they thought these visualizations were too complex to understand or because they were not attractive.

The reflection task was perceived as slightly more difficult than the coding task. Overall, 32% of the students thought that the reflection task was difficult. Some of the students reported that they did not always know how to answer the open-ended questions and sometimes they did not reach a consensus in their group. Meanwhile, most of the students (89%) thought that the reflection task was helpful for improving their group talk.

Usability evaluation

We gave the students 10 minutes to finish the talk analysis group activity. On average, they took 3.8 ($SD = 1.6$), 1.8 ($SD = 0.8$), and 2.0 ($SD = 1.0$) minutes and produced 22 ($SD = 22$), 19 ($SD = 14$), and 19 ($SD = 12$) turns for the coding, visualization, and reflection steps, respectively. In the coding step, around half of the groups engaged in high-level cognitive discussions. Some of the groups had emergent reflections about their participation equality and problem-solving. In the visualization step, almost all of the groups (90%) conducted within-group comparisons, and around half discussed their overall performance as a group. In the reflection step, most of the groups (75%) referred to visualizations to answer the reflection sheet, but very few of the groups (10%) discussed reasons for their relatively lower usage of some tools. After finishing the task, half of the groups spontaneously explored the visualizations again in the time that was left. In the following discussion, we focus on group 18 to explore students' dynamic interactions with iTalk–iSee.

Group 18 produced 67 turns in total, with 24 turns (4.5 min), 19 turns (2 min), and 20 turns (2 min) for the coding, visualization, and reflection steps, respectively. For the coding step, we selected a 12-turn problem-solving talk segment for group 18. Table 3 presents some utterances of this segment. Wang pointed out that there were more than two adults, which suggested that they could take one child for free (#7). Xing did not respond to her and expressed his idea directly that did not differentiate children and adults and counted the total number of people directly (#8). Wang immediately interrupted by saying "No" (#9). This statement indicated her disagreement with Xing's idea. However, Xing did not stop and kept on elaborating his own idea (#10). Wang then strongly reminded him of the task requirement (#11). Xing finally responded to Wang and proposed a possible strategy (#12).

The selected excerpt on coding (see Table 4) shows the students' discussion around the utterance of "No." After a few seconds of group silence, Pan suggested that "No" should

Table 3 "No" in the selected discussion segment for coding

Turn	Speaker	Content
#7	Wang	First, we know there are three adults in total, which is more than two.
#8	Xing	Three plus fourteen, fourteen, we can get this.
➡#9	Wang	No.
#10	Xing	It's 17.
#11	Wang	A plan with the minimum cost! A plan with the minimum cost!
#12	Xing	Right. We can try one by one, yes?

Table 4 Excerpt on coding: "'No' should be…"

Turn	Start time	End time	Speaker	Content	Embodied actions
#5	0:01:21	0:01:22	Xing	"No" should be…	
#6	0:01:26	0:01:28	Pan	It should be "build on others."	(#6) Xing (the left) looked at Pan (the right)
#7	0:01:28	0:01:28	Xing	No.	
#8	0:01:29	0:01:29	Wang	"None"?	(#8) Wang (the middle) looked at Xing
#9	0:01:30	0:01:33	Xing	It should be "explain oneself" because, because you said you were wrong about this.	
#10	0:01:35	0:01:35	Pan	Yes.	(#9) Xing leaned back and looked at Wang

be coded as "build on others" (#6). Xing immediately disagreed with this (#7). Wang then suggested to Xing that it possibly did not contain any I-Talk tool (#8). Xing immediately suggested the code "explain oneself" instead and provided his reason, which revealed that he possibly did not realize that the original "No" by Wang was actually a disagreement to his idea (#9). However, the suggested code "explain oneself" seemed persuasive and received vocal agreement by Pan (#10). Wang also nodded her head and then pressed the button "explain oneself" on the tablet. Although Wang felt that she had not used a I-Talk tool in the utterance of "No", she was not sure about her viewpoint and could not persuade the others. This group also skipped discussing the reference codes provided by the teacher and therefore was unable to properly code this utterance.

This excerpt demonstrates that the coding step in iTalk–iSee was able to guide the students to think over and talk about the various talk tools in an authentic context. However, the primary school students still had difficulties in understanding and differentiating the

Table 5 Excerpt on visualization: "This is the average of us"

Turn	Start time	End time	Speaker	Content	Embodied actions
#28	0:04:01	0:04:06	Xing	Have a look at mine.	
#29	0:04:06	0:04:07	Pan	I don't have any!	
#30	0:04:07	0:04:23	Xing	No. This is mine. This is yours. This is yours. This is the average of us. Have a look at mine. 100, 84, 80, 79, 100, 100.	(#29) Pan (the right) pointed at the five-pointed star. Xing (the left) and Wang (the middle) looked at the tablet.
#31	0:04:26	0:04:27	Pan	You are 100, 41.	
#32	0:04:28	0:04:37	Xing	Hey, hey. Yours is 100, 60, 0, 0, 0. Next page. Ours exceed the averages here.	
#33	0:04:40	0:04:42	Pan	Look at yours first.	
#34	0:04:43	0:04:48	Xing	Mine exceed the averages a lot. Exceed a lot. Exceed, exceed—all of mine exceed the averages.	(#30) Xing pressed avatars of the members. All members looked at the tablet.
#35	0:04:53	0:04:53	Wang	Awesome, awesome.	

Fig. 5 I-Talk five-pointed star of Pan in the selected group

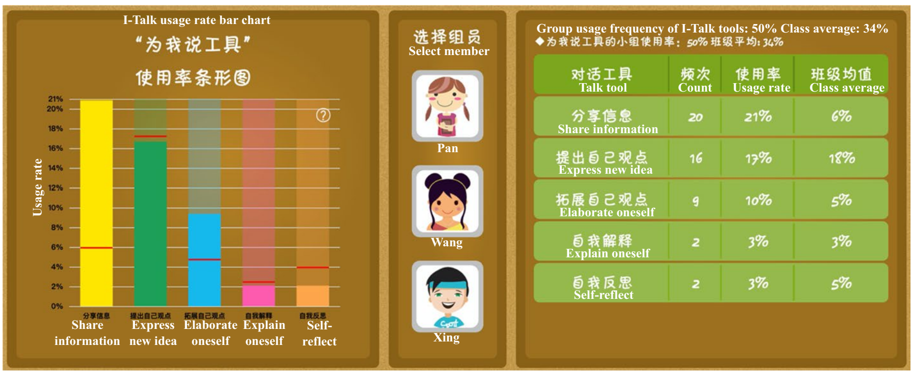

Fig. 6 I-Talk usage rate bar chart of the selected group

Table 6 Excerpt on reflection: “We can do more self-reflection”

Turn	Start time	End time	Speaker	Content	Embodied actions
#58	0:07:52	0:07:55	Xing	Seldom use… what did we use. It should be “explain oneself.”	
#59	0:07:56	0:07:57	Wang	“Self-reflect.”	
#60	0:07:58	0:07:58	Xing	Oh, “self-reflect.”	(#60) Xing (the left) looked at the tablet.
#61	0:08:07	0:08:08	Wang	Five-pointed star.	
#62	0:08:11	0:08:12	Pan	How do we write this?	
#63	0:08:14	0:08:16	Xing	We can do more self-reflection.	(#63) Xing stood up and looked at Pan (the right) and Wang (the middle).

various I-Talk tools after the first brief introduction. Therefore, the students need additional explicit guidance on these talk tools after their coding practice.

The excerpt on visualization (see Table 5) reveals how the group engaged with the five-pointed star (see Fig. 5) and usage rate bar chart (see Fig. 6). The statistical tables underlying the visualizations were also provided to facilitate students’ reading of the visualizations and understanding of their performance. When Xing suggested looking at his visualizations, Pan interacted with iTalk–iSee and was surprised that she had no usage of I-Talk (#29). This was immediately clarified by Xing, who explained to the group how to interact with iTalk–iSee and get individual and group visualizations (#30). Pan then pressed the buttons to show the five-pointed star and the corresponding scores for Wang (#31). Xing laughed and interacted with iTalk–iSee to show the performance of Pan (#32). When they moved on and engaged with the bar chart, the group noticed their overall performance compared with the class averages (#32). Pan then suggested looking at their individual performance again (#33). Xing had an impressive usage of all I-Talk tools, which Wang immediately complimented (#35).

This segment indicates that the visualization step of iTalk–iSee was able to guide the students to intuitively position their overall performance against the teacher-set standards and the class averages. In addition, within their groups, the students were able to correctly explore the visualizations without explicit instructions. For example, they could figure out how to select members and how to read the complementary statistical tables. They were also eager to find out their own performance, which they tended to compare with others’. These visualization-oriented discussions helped to strengthen the students’ awareness of both their group’s and their own performance.

The excerpt on reflection shows how the group identified the tool that they used least (see Table 6). Xing suggested the tool “explain oneself” to Pan, who was about to fill out the sheet (#58). Wang suggested “self-reflect” instead (#59), to which Xing immediately agreed after rechecking the visualizations (#60). Wang further suggested that Pan choose the five-pointed star to support their choice (#61). Pan then asked about the open-ended question in the reflection sheet (#62). They did not discuss possible reasons for the rare usage of "self-reflect." Xing directly suggested that they should use more "self-reflect" later (#63), which was a general suggestion and did not specify how to improve the usage rate.

This segment indicates that the reflection step in iTalk–iSee was able to guide the students back to the visualizations and think about their overall performance. In addition, they were able to use appropriate visualizations to justify their choices. However, it was difficult for them to discuss possible reasons for the limited usage of a certain tool and how to improve the usage. In addition, it was still challenging for the students to differentiate the quality and usage rate of a tool. The first reflection question intended to guide the students back to the five-pointed star to examine their performance against the teacher-set standards, while the second reflection question intended to guide the students back to the bar chart or bubble plot to examine their usage rates of various tools. The students had no problem with identifying the tool(s) that met the badge standards according to the five-pointed star. However, group 18 and most of the other groups still referred to the five-pointed star for the second question and chose the least qualified rather than the least used tool. Therefore, the students required additional explanations of the difference between these two reflection questions and how to make full use of the various visualizations.

Discussion

This paper describes the design and application of the participatory visual learning analytical tool, iTalk–iSee, which aims to facilitate student learning and the use of peer talk tools in DCPS. iTalk–iSee includes various visual representations of collaborative discourse to allow students to intuitively see their collaboration and promote productive and reflective discussions about their performance. It contributes some unique design features to the field of computer-supported collaborative learning, which makes it a promising tool for young learners across subjects and cultures.

Design features of iTalk–iSee

Firstly, iTalk–iSee supports productive peer talk in a face-to-face context. Most visual learning analytical tools focus on the online context and embed productive peer talk moves into their interfaces as micro-scripts, sentence openers, or questioning scaffolds to facilitate online communication (e.g., Avcı, 2020; Bouyias & Demetriadis, 2012; Popov et al., 2019). Few visual analytical tools are available to support face-to-face productive peer talk, and many long-term face-to-face peer talk intervention programs in normal classroom settings lack technical support (e.g., Clark et al., 2003; Littleton & Mercer, 2013; Topping & Trickey, 2013). iTalk–iSee provides a systematic technical supplement to such intervention programs for face-to-face peer talk. It provides enriched visual representations and a structured analytical framework to engage students in analyzing and reflecting on their group talk in one or more tasks.

Secondly, iTalk–iSee is firmly rooted in the theory of DCPS and incorporates various thoughtfully designed visual representations. It is a challenge for the development of visual learning analytical tools to consider both learning and visualization theories (Hu & Chen, 2021; Vieira et al., 2018). iTalk–iSee becomes an example for developing such tools rooted in best practices from both the learning and visualization communities. It is based on Bakhtinian dialogism, which emphasizes the central role of dialogue in learning (Bakhtin, 1929/1981). iTalk–iSee enables observable productive peer talk moves to be mapped onto four talk virtues of DCPS: equality, respect, open-mindedness, and convergence. It further structures and conceptualizes productive peer talk moves as three types of talk tools to help students achieve the goals and talk virtues of dialogic collaboration. The underlying theoretical framework (see Fig. 2) may also inform prospective peer talk intervention programs in the context of DCPS. iTalk–iSee is also characterized by its variety of visual feedback. These visualizations can inspire productive dialogue among students by providing them with intuitive, comprehensive, and interactive analysis results (Nagy, 2016). Visual feedback is more effective in enhancing students' interactions than textual or no feedback (Lim et al., 2014). Visual feedback can also trigger and sustain students' regulated learning (Hadwin et al., 2018). iTalk–iSee follows specific psychological principles for effective graphic design (Kosslyn, 2006). It fully considers the typical characteristics of primary school students, includes suitable visualization types and colors, adopts visual embellishments, features synchronized and complementary multiple visual representations, and provides reference frames to engage young learners in interacting with the visualizations and promotes their visual understanding.

Thirdly, iTalk–iSee has friendly and structured interfaces to engage students in coding their collaborative discourse. Instead of providing ready-to-use analytical feedback to students, iTalk–iSee involves students in the analysis by engaging them in the underlying coding process. Coding-and-counting is a widely used discourse analysis approach that has been embedded in many visual learning analytical tools on discourse (Chen & Zhang, 2016; Chen et al., 2015; Van Leeuwen et al., 2014). However, such analytical process is largely invisible to learners. In contrast, as one of the first tools of its kind, iTalk–iSee not only makes this underlying analytical process visible but also guides learners to participate in it. Such participatory analytics may offer a solution to challenges regarding students' lack of awareness of design intentions (Wise, 2014) and their distrust of the usefulness and authenticity of analytics (Schnaubert & Bodemer, 2019). They may also help students understand why and how the analysis is produced and how they can utilize the information to improve their collaborations. This coding process can reveal students' misconceptions, allowing teachers the opportunity to provide further guidance. Students may also deepen their understanding of talk tools and increase their awareness of tool usage when discussing their talk and comparing their codes to the reference. Therefore, this participatory visual learning analytics approach is promising and can inform a new line of inquiry regarding how to facilitate collaborative learning by engaging students in analyzing and reflecting on their collaboration in the field of computer-supported collaborative learning.

Limitations and future research

The application of iTalk–iSee is limited by several challenges concerning teacher guidance, data collection, transcription, and coding. The current version of iTalk–iSee teaches students about productive peer talk but does not support independent group use. It must still incorporate teacher guidance on how to understand the talk virtues in DCPS, how to use the talk tools to achieve these talk virtues, how to code each turn, and how to interpret the various visualizations. For example, it is important to quickly clarify students' misunderstandings of codes as revealed by the coding process. The talk network, though simplified, still requires a detailed explanation, as it is complex and unfamiliar to young students.

Another major challenge concerns data collection and analysis. iTalk–iSee supports the analysis of face-to-face peer talk in normal classroom settings. However, it is challenging to capture high-quality videos of multiple groups in a normal classroom setting, which is noisy during collaborative activities. Transcribing the videos manually is also labor-intensive and time-consuming. Advanced speech processing and speaker identification techniques may help address this issue (e.g., Donnelly et al., 2017; Hung et al., 2011; Tirumala et al., 2017; Valente & Vinciarelli, 2010). However, these techniques rely on high-quality audio recordings, which are challenging and expensive to obtain.

The fine-grained coding-and-counting is also a time-consuming and labor-intensive process (Chen et al., 2015); thus, the timeliness of feedback is limited. Although involving students in coding the discourse is a potential solution, it is challenging for primary school students to properly code their talk. Sufficient teaching and cross-validation are required to verify coding accuracy. Future studies could adopt peer evaluations to help improve accuracy. In our project, we relied on the professional coding of well-trained adult coders due to the tight course schedule and large coding workload. We also developed a complementary data collection and pre-processing module for iTalk–iSee that immediately uploads the class videos collected for manual transcription and then structures the videos and transcripts in a corresponding coding tool to facilitate coding. This underlying module of iTalk–iSee helps relieve pressure to provide timely feedback. Further advances in natural language processing techniques might help alleviate part of the coding workload (e.g., Devlin et al., 2019; Mu et al., 2012; Sullivan & Keith, 2019).

There are several directions for future research to further improve iTalk–iSee. Firstly, prospective studies could continuously adjust or improve the design of iTalk–iSee by applying it to various contexts. We refined the design details of iTalk–iSee through a semester-long design-based peer talk intervention program in the context of mathematical problem-solving for fourth-grade pupils. However, iTalk–iSee aims to support general subjects for young learners. Additional empirical studies to evaluate its application in other contexts are needed. Secondly, efforts could be made to adapt iTalk–iSee to online contexts. iTalk–iSee aims to provide posthoc visual analytical feedback for groups, which should also be applicable to online collaborations. It may be possible to embed iTalk–iSee into online discussion applications as a visual reflective tool to support online productive peer interactions. Thirdly, iTalk–iSee could be developed into a learning community platform to scale and sustain its usage. In an online open learning community, learners could upload and share their collaboration videos and personalized visualizations. They could also comment on the collaborations of other groups and interact with friends. This playing and sharing culture could sustain the development of iTalk–iSee and form a self-organized learning community for productive peer talk.

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Declarations

Conflict of Interest The authors declare that there is no conflict of interest.

References

Agar, M. (2006). An ethnography by any other name … *Forum Qualitative Sozialforschung / Forum: Qualitative Social Research*, *7*(4). https://doi.org/10.17169/fqs-7.4.177

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction, 16*(3), 183–198. https://doi.org/10.1016/j.learninstruc.2006.03.001

Ainsworth, S. (2014). The multiple representation principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 464–486). Cambridge University Press. https://doi.org/10.1007/978-1-4020-5267-5_9

Alper, B., Riche, N. H., Chevalier, F., Boy, J., & Sezgin, M. (2017). Visualization literacy at elementary school. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (pp. 5485–5497). ACM. https://doi.org/10.1145/3025453.3025877

Asterhan, C. S. C., & Schwarz, B. B. (2009). Argumentation and explanation in conceptual change: Indications from protocol analyses of peer-to-peer dialog. *Cognitive Science, 33*(3), 374–400. https://doi.org/10.1111/j.1551-6709.2009.01017.x

Avcı, Ü. (2020). Examining the role of sentence openers, role assignment scaffolds and self-determination in collaborative knowledge building. *Educational Technology Research and Development, 68*(1), 109–135. https://doi.org/10.1007/s11423-019-09672-5

Baker, M. J., Andriessen, J., & Schwarz, B. B. (2020). Collaborative argumentation-based learning. In N. Mercer, R. Wegerif, & L. Major (Eds.), *The Routledge international handbook of research on dialogic education* (pp. 76–88). Routledge.

Baker, M. J., Schwarz, B. B., & Ludvigsen, S. R. (2021). Educational dialogues and computer supported collaborative learning: Critical analysis and research perspectives. *International Journal of Computer-Supported Collaborative Learning, 16*, 583–604. https://doi.org/10.1007/s11412-021-09359-1

Bakhtin, M. M. (1929/1984). *Problems of Dostoevsky's poetics* (C. Emerson, Ed., Trans.). Manchester University Press.

Bakhtin, M. M. (1981). *The dialogic imagination*. University of Texas Press.

Bakhtin, M. M. (1999). *Problems of Dostoevsky's poetics*. University of Minnesota Press.

Bangor, A., Kortum, P. T., & Miller, J. T. (2008). An empirical evaluation of the system usability scale. *International Journal of Human-Computer Interaction, 24*(6), 574–594.

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences, 12*(3), 307–359.

Bateman, S., Mandryk, R. L., Gutwin, C., Genest, A., McDine, D., & Brooks, C. (2010). Useful junk? The effects of visual embellishment on comprehension and memorability of charts. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 2573–2582). ACM. https://doi.org/10.1145/1753326.1753716

Bertsch, S., Pesta, B. J., Wiscott, R., & McDaniel, M. A. (2007). The generation effect: A meta-analytic review. *Memory & Cognition, 35*, 201–210. https://doi.org/10.3758/BF03193441

Borge, M., & Carroll, J. M. (2014). Verbal equity, cognitive specialization, and performance. In *Proceedings of the 18th International Conference on Supporting Group Work* (pp. 215–225). New York, NY: ACM.

Borge, M., Ong, Y. S., & Rosé, C. P. (2018). Learning to monitor and regulate collective thinking processes. *International Journal of Computer-Supported Collaborative Learning, 13*, 61–92. https://doi.org/10.1007/s11412-018-9270-5

Borgo, R., Abdul-Rahman, A., Mohamed, F., Grant, P. W., Reppa, I., Floridi, L., & Chen, M. (2012). An empirical study on using visual embellishments in visualization. *IEEE Transactions on Visualization and Computer Graphics, 18*(12), 2759–2768. https://doi.org/10.1109/TVCG.2012.197

Borkin, M. A., Vo, A. A., Bylinskii, Z., Isola, P., Sunkavalli, S., Oliva, A., & Pfister, H. (2013). What makes a visualization memorable? *IEEE Transactions on Visualization and Computer Graphics, 19*(12), 2306–2315.

Bouyias, Y., & Demetriadis, S. (2012). Peer-monitoring vs. micro-script fading for enhancing knowledge acquisition when learning in computer-supported argumentation environments. *Computers and Education, 59*(2), 236–249. https://doi.org/10.1016/j.compedu.2012.01.001

Bridges, S. M., Hmelo-Silver, C. E., Chan, L. K., Green, J. L., & Saleh, A. (2020). Dialogic intervisualizing in multimodal inquiry. *International Journal of Computer-Supported Collaborative Learning, 15*(3), 283–318.

Byun, H., Lee, J., & Cerreto, F. A. (2014). Relative effects of three questioning strategies in ill-structured, small group problem solving. *Instructional Science, 42*(2), 229–250. https://doi.org/10.1007/s11251-013-9278-1

Cai, J. (2000). Mathematical thinking involved in US and Chinese students' solving of process-constrained and process-open problems. *Mathematical Thinking and Learning, 2*(4), 309–340.
Chen, B., & Zhang, J. (2016). Analytics for knowledge creation: Towards epistemic agency and design mode thinking. *Journal of Learning Analytics, 3*(2), 139–163.
Chen, G., Clarke, S. N., & Resnick, L. B. (2015). Classroom Discourse Analyzer (CDA): A discourse analytic tool for teachers. *Technology, Instruction, Cognition and Learning, 10*, 85–105.
Chi, M. T., & Menekse, M. (2015). Dialogue patterns in peer collaboration that promote learning. In L. B. Resnick, C. S. C. Asterhan, & S. N. Clarke (Eds.), *Socializing intelligence through academic talk and dialogue* (pp. 263–274). American Educational Research Association.
Chiu, M. M., & Khoo, L. (2003). Rudeness and status effects during group problem solving: Do they bias evaluations and reduce the likelihood of correct solutions? *Journal of Educational Psychology, 95*(3), 506–523. https://doi.org/10.1037/0022-0663.95.3.506
Chiu, T. K. F., & Mok, I. A. C. (2017). Learner expertise and mathematics different order thinking skills in multimedia learning. *Computers and Education, 107*, 147–164. https://doi.org/10.1016/j.compedu.2017.01.008
Clark, A. M., Anderson, R. C., Kuo, L.-J., Kim, I.-H., Archodidou, A., & Nguyen-Jahiel, K. (2003). Collaborative reasoning: Expanding ways for children to talk and think in schools. *Educational Psychology Review, 15*(2), 181–198.
Devlin, J., Chang, M. W., Lee, K., & Toutanova, K. (2019). BERT: Pre-training of deep bidirectional transformers for language understanding. In *Proceedings of the 2019 Conference of the North American Chapter of the Association for Computational Linguistics: Human Language Technologies* (pp. 4171–4186). Minneapolis, MN, USA: Association for Computational Linguistics. https://www.aclweb.org/anthology/N19-1423.
Dewolf, T., Van Dooren, W., & Verschaffel, L. (2015). Mathematics word problems illustrated: An analysis of Flemish mathematics textbooks. *Mediterranean Journal for Research in Mathematics Education, 14*, 17–42.
Dillenbourg, P., Lemaignan, S., Sangin, M., Nova, N., & Molinari, G. (2016). The symmetry of partner modelling. *International Journal of Computer-Supported Collaborative Learning, 11*(2), 227–253. https://doi.org/10.1007/s11412-016-9235-5
Donnelly, P. J., Blanchard, N., Olney, A. M., Kelly, S., Nystrand, M., & D'Mello, S. K. (2017). Words matter: Automatic detection of teacher questions in live classroom discourse using linguistics, acoustics, and context. In *Proceedings of the Seventh International Learning Analytics & Knowledge Conference* (pp. 218–227). New York, NY: ACM.
Echeverria, V., Martinez-Maldonado, R., Buckingham Shum, S., Chiluiza, K., Granda, R., & Conati, C. (2018). Exploratory versus explanatory visual learning analytics: Driving teachers' attention through educational data storytelling. *Journal of Learning Analytics*, *5*(3). https://doi.org/10.18608/jla.2018.53.6
Edmondson, A. (1999). Psychological safety and learning behavior in work teams. *Administrative Science Quarterly, 44*(2), 350–383.
Friend, M., & Cook, L. (1992). *Interactions: Collaboration skills for school professionals*. Longman.
Galesic, M., & Garcia-Retamero, R. (2011). Graph literacy: A cross-cultural comparison. *Medical Decision Making, 31*(3), 444–457. https://doi.org/10.1177/0272989X10373805
Gašević, D., Joksimović, S., Eagan, B. R., & Shaffer, D. W. (2018). SENS: Network analytics to combine social and cognitive perspectives of collaborative learning. *Computers in Human Behavior, 92*, 562–577. https://doi.org/10.1016/j.chb.2018.07.003
Gillies, R. M. (2019). Promoting academically productive student dialogue during collaborative learning. *International Journal of Educational Research, 97*(2019), 200–209. https://doi.org/10.1016/j.ijer.2017.07.014
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). Routledge.
González-Howard, M. (2019). Exploring the utility of social network analysis for visualizing interactions during argumentation discussions. *Science Education, 103*(3), 503–528. https://doi.org/10.1002/sce.21505
Hadwin, A. F., Bakhtiar, A., & Miller, M. (2018). Challenges in online collaboration: Effects of scripting shared task perceptions. *International Journal of Computer-Supported Collaborative Learning, 13*(3), 301–329. https://doi.org/10.1007/s11412-018-9279-9
Hillaire, G., Rappolt-Schlichtmann, G., & Ducharme, K. (2016). Prototyping visual learning analytics guided by an educational theory informed goal. *Journal of Learning Analytics*, *3*(3), 115–142. https://doi.org/10.18608/jla.2016.33.7
Hmelo-silver, C. E., Liu, L., & Jordan, R. (2009). Visual representation of a multidimensional coding scheme for understanding technology-mediated learning about complex natural systems. *Computers & Education, 4*(3), 253–280.

Hu, L., & Chen, G. (2022). *A systematic review and meta-analysis of productive peer talk moves*. [Manuscript submitted for publication]. Faculty of Education. The University of Hong Kong.

Hu, L., & Chen, G. (2021). A systematic review of visual representations of collaborative discourse. *Educational Research Review, 34*(July), 100403. https://doi.org/10.1016/j.edurev.2021.100403

Hu, L., Chen, G., Li, P., & Huang, J. (2021). Multimedia effect in problem solving: A meta-analysis. *Educational Psychology Review*. https://doi.org/10.1007/s10648-021-09610-z

Hung, H., Huang, Y., Friedland, G., & Gatica-Perez, D. (2011). Estimating dominance in multi-party meetings using speaker diarization. *IEEE Transactions on Audio, Speech and Language Processing, 19*(4), 847–860. https://doi.org/10.1109/TASL.2010.2066267

Johnson, D. W., & Johnson, R. T. (1989). Social skills for successful group work. *Educational Leadership, 47*(4), 29–34.

Kapur, M., Voiklis, J., & Kinzer, C. K. (2008). Sensitivities to early exchange in synchronous computer-supported collaborative learning (CSCL) groups. *Computers & Education, 51*(1), 54–66. https://doi.org/10.1016/j.compedu.2007.04.007

Keim, D., Mansmann, F., & Thomas, J. (2009). Visual analytics: How much visualization and how much analytics? *ACM SIGKDD Explorations Newsletter, 11*(2), 5–8. https://doi.org/10.1145/1809400.1809403

King, A. (1997). ASK to THINK-TEL WHY: A model of transactive peer tutoring for scaffolding higher level complex learning. *Educational Psychologist, 32*(4), 221–235.

Kirilenko, A. P., & Stepchenkova, S. (2016). Inter-coder agreement in one-to-many classification: Fuzzy kappa. *PLoS ONE, 11*(3), 1–15. https://doi.org/10.1371/journal.pone.0149787

Koschmann, T., & Schwarz, B. B. (2021). Case studies in theory and practice. In U. Cress, J. Oshima, C. Rosé, & A. Wise (Eds.), *International Handbook of Computer-Supported Collaborative Learning* (pp. 463–478). Springer.

Kosslyn, S. M. (2006). *Graph design for the eye and the mind*. Oxford University Press.

Lenzner, A., Schnotz, W., & Müller, A. (2013). The role of decorative pictures in learning. *Instructional Science, 41*(5), 811–831. https://doi.org/10.1007/s11251-012-9256-z

Leslie, K. C., Low, R., Jin, P., & Sweller, J. (2012). Redundancy and expertise reversal effects when using educational technology to learn primary school. *Bulgarian Journal of Agricultural Science, 18*(2), 197–206.

Lexico (n.d.). *Tool*. Retrieved August 13, 2021, from https://www.lexico.com/definition/tool

Lim, K. Y., Park, H., & Kim, H. (2014). Effects of social network-based visual feedback on learning in online discussion. *Journal of Educational Technology, 30*(3), 443–466.

Littleton, K., & Mercer, N. (2013). *Interthinking: Putting talk to work*. Routledge.

Liu, S., Song, Y., Zhou, M. X., Pan, S., Qian, W., Cai, W., & Lian, X. (2012). TIARA: Interactive, topic-based visual text summarization and analysis. *ACM Transactions on Intelligent Systems and Technology, 3*(2), 1–28. https://doi.org/10.1145/2089094.2089101

Mather, M., & Nesmith, K. (2008). Arousal-enhanced location memory for pictures. *Journal of Memory and Language, 58*(2), 449–464.

Martinez-Maldonado, R., Gašević, D., Echeverria, V., Fernandez Nieto, G., Swiecki, Z., & Buckingham Shum, S. (2021). What do you mean by collaboration analytics? A conceptual model. *Journal of Learning Analytics*, *8*(1), 126–153. https://doi.org/10.18608/jla.2021.7227

Mayer, R. E. (2014a). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 43–71). Cambridge University Press.

Mayer, R. E. (2014b). Principles based on social cues in multimedia learning: Personalization, voice, image, and embodiment principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 345–368). Cambridge University Press.

Mayer, R. E., & Fiorella, L. (2014). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity, and temporal contiguity principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 279–315). Cambridge University Press.

Mayer, R. E. & Pilegard, C. (2014). Principles for managing essential processing in multimedia learning: Segmenting, pretraining, and modality principles. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed; pp. 316–344). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.017

Ministry of Education. (2013a). *Mathematics (fourth grade, 1st volume)*. Jiangsu Phoenix Education Press.

Ministry of Education. (2013b). *Mathematics (fourth grade, 2nd volume)*. Jiangsu Phoenix Education Press.

Mu, J., Stegmann, K., Mayfield, E., Rosé, C., & Fischer, F. (2012). The ACODEA framework: Developing segmentation and classification schemes for fully automatic analysis of online discussions. *International Journal of Computer-Supported Collaborative Learning, 7*(2), 285–305. https://doi.org/10.1007/s11412-012-9147-y

Nagy, R. (2016). Tracking and visualizing student effort : Evolution of a practical analytics tool for staff and student engagement. *Journal of Learning Analytics*, *3*(2), 165–193. https://doi.org/10.18608/jla.2016.32.8

Nievelstein, F., van Gog, T., van Dijck, G., & Boshuizen, H. P. A. (2013). The worked example and expertise reversal effect in less structured tasks: Learning to reason about legal cases. *Contemporary Educational Psychology, 38*(2), 118–125. https://doi.org/10.1016/j.cedpsych.2012.12.004

Noroozi, O., Teasley, S. D., Biemans, H. J., Weinberger, A., & Mulder, M. (2013). Facilitating learning in multidisciplinary groups with transactive CSCL scripts. *International Journal of Computer-Supported Collaborative Learning, 8*(2), 189–223.

OECD. (2017). *PISA 2015 assessment and analytical framework: Science, reading, mathematic, financial literacy and collaborative problem solving*. PISA, OECD Publishing. https://doi.org/10.1787/9789264281820-en

Park, B., Moreno, R., Seufert, T., & Brünken, R. (2011). Does cognitive load moderate the seductive details effect? A multimedia study. *Computers in Human Behavior, 27*(1), 5–10. https://doi.org/10.1016/j.chb.2010.05.006

Piaget, J. (1932). *The moral development of the child*. Kegan Paul.

Popov, V., Biemans, H. J. A., Fortuin, K. P. J., van Vliet, A. J. H., Erkens, G., Mulder, M., Jaspers, J., & Li, Y. (2019). Effects of an interculturally enriched collaboration script on student attitudes, behavior, and learning performance in a CSCL environment. *Learning, Culture and Social Interaction, 21*, 100–123. https://doi.org/10.1016/j.lcsi.2019.02.004

Rau, M. A. (2013). *Conceptual learning with multiple graphical representations: Intelligent tutoring systems support for sense-making and fluency-building processes* (Doctoral disertation, Carnegie Mellon University). ProQuest Dissertations and Theses.

Rau, M. A. (2017). Conditions for the effectiveness of multiple visual representations in enhancing STEM learning. *Educational Psychology Review, 29*(4), 717–761. https://doi.org/10.1007/s10648-016-9365-3

Rau, M. A., Aleven, V., & Rummel, N. (2015). Successful learning with multiple graphical representations and self-explanation prompts. *Journal of Educational Psychology., 107*(1), 30. https://doi.org/10.1037/a0037211

Reichheld, F. F. (2003). The one number you need to grow. *Harvard Business Review, 81*(12), 46–55.

Roberts, J., & Lyons, L. (2017). The value of learning talk: Applying a novel dialogue scoring method to inform interaction design in an open-ended, embodied museum exhibit. *International Journal of Computer-Supported Collaborative Learning, 12*(4), 343–376. https://doi.org/10.1007/s11412-017-9262-x

Ryan, L. (2016). *The visual imperative: Creating a visual culture of data discovery*. Morgan Kaufmann.

Schnaubert, L., & Bodemer, D. (2019). Providing different types of group awareness information to guide collaborative learning. *International Journal of Computer-Supported Collaborative Learning, 14*(1), 7–51. https://doi.org/10.1007/s11412-018-9293-y

Schneider, S., Nebel, S., & Rey, G. D. (2016). Decorative pictures and emotional design in multimedia learning. *Learning and Instruction, 44*, 65–73. https://doi.org/10.1016/j.learninstruc.2016.03.002

Schwartz, N. (2020). Making the invisible visible: Practical applications of visual metaphors in teaching and learning accounting. *Journal of Visual Literacy, 39*(1), 49–71. https://doi.org/10.1080/1051144X.2020.1737906

Schwonke, R., Berthold, K., & Renkl, A. (2009). How multiple external representations are used and how they can be made more useful. *Applied Cognitive Psychology, 23*, 1227–1243. https://doi.org/10.1002/acp

Shaffer, D. W., & Ruis, A. R. (2017). Epistemic network analysis: A worked example of theory-based learning analytics. In C. Lang, G. Siemens, A. F. Wise, & D. Gasevic (Eds.), *Handbook of learning analytics* (pp. 175–187). Society for Learning Analytics Research (SoLAR).

Silver, E. A., Leung, S. S., & Cai, J. (1995). Generating multiple solutions for a problem: A comparison of the responses of US and Japanese students. *Educational Studies in Mathematics, 28*(1), 35–54.

Simms, A., & Nichols, T. (2014). Social loafing: A review of the literature. *Journal of Management Policy and Practice, 15*(1), 58.

Simoff, S., Böhlen, M., & Mazeika, A. (2008). Visual data mining: An introduction and overview. In S. Simoff, M. Böhlen, & A. Mazeika (Eds.), *Visual data mining* (Vol. 4404, pp. 1–12). Springer.

Strauß, S., & Rummel, N. (2021). Promoting regulation of equal participation in online collaboration by combining a group awareness tool and adaptive prompts. But does it even matter? *International Journal of Computer-Supported Collaborative Learning, 16*(1), 67–104.

Strmecki, D., Bernik, A., & Radosevic, D. (2015). Gamification in e-learning: Introducing gamified design elements into e-learning systems. *Journal of Computer Science, 11*(12), 1108–1117.

Sullivan, F. R., & Keith, P. K. (2019). Exploring the potential of natural language processing to support microgenetic analysis of collaborative learning discussions. *British Journal of Educational Technology, 50*(6), 3047–3063. https://doi.org/10.1111/bjet.12875

Swiecki, Z. (2021). Measuring the impact of interdependence on individuals during collaborative problem-solving. *Journal of Learning Analytics, 8*(1), 75–94.

Tegos, S., Demetriadis, S., & Karakostas, A. (2015). Promoting academically productive talk with conversational agent interventions in collaborative learning settings. *Computers and Education, 87*, 309–325. https://doi.org/10.1016/j.compedu.2015.07.014

Thompson, D. S., & Beene, S. (2020). Uniting the field: Using the ACRL Visual Literacy Competency Standards to move beyond the definition problem of visual literacy. *Journal of Visual Literacy, 39*(2), 73–89. https://doi.org/10.1080/1051144X.2020.1750809

Tirumala, S. S., Shahamiri, S. R., Garhwal, A. S., & Wang, R. (2017). Speaker identification features extraction methods: A systematic review. *Expert Systems with Applications, 90*, 250–271. https://doi.org/10.1016/j.eswa.2017.08.015

Topping, K. J., & Trickey, S. (2013). The role of dialog in philosophy for children. *International Journal of Educational Research, 63*, 69–78. https://doi.org/10.1016/j.ijer.2013.01.002

Trausan-Matu, S., Wegerif, R., & Major, L. (2021). Dialogism. In U. Cress, J. Oshima, C. Rosé, & A. Wise (Eds.), *International Handbook of Computer-Supported Collaborative Learning* (pp. 219–239). Springer International Publishing.

Tufte, E. R. (1983). *The visual display of quantitative information*. Graphics Press.

Valente, F., & Vinciarelli, A. (2010). Improving speech processing through social signals: Automatic speaker segmentation of political debates using role based turn-taking patterns. In *Proceedings of the 2nd International Workshop on Social Signal Processing* (pp. 29–34). New York: ACM. https://doi.org/10.1145/1878116.1878128

Van Leeuwen, A., Janssen, J., Erkens, G., & Brekelmans, M. (2014). Supporting teachers in guiding collaborating students: Effects of learning analytics in CSCL. *Computers and Education, 79*, 28–39. https://doi.org/10.1016/j.compedu.2014.07.007

Vieira, C., Parsons, P., & Byrd, V. (2018). Visual learning analytics of educational data: A systematic literature review and research agenda. *Computers and Education, 122*, 119–135. https://doi.org/10.1016/j.compedu.2018.03.018

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press. https://doi.org/10.1007/978-3-540-92784-6

Webb, N. M., Franke, M. L., Ing, M., Wong, J., Fernandez, C. H., Shin, N., & Turrou, A. C. (2014). Engaging with others' mathematical ideas: Interrelationships among student participation, teachers' instructional practices, and learning. *International Journal of Educational Research, 63*, 79–93. https://doi.org/10.1016/j.ijer.2013.02.001

Wegerif, R. (2020). Towards a dialogic theory of education for the internet age. In N. Mercer, R. Wegerif, & L. Major (Eds.), *The Routledge international handbook of research on dialogic education* (pp. 14–26). Routledge.

Weinberger, A., Stegmann, K., & Fischer, F. (2007). Knowledge convergence in collaborative learning: Concepts and assessment. *Learning and Instruction, 17*(4), 416–426.

Wiley, J., Sanchez, C. A., & Jaeger, A. J. (2014). The individual differences in working memory capacity principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 598–620). Cambridge University Press.

Wise, A. F. (2014). Designing pedagogical interventions to support student use of learning analytics. In *Proceedings of the Fourth International Conference on Learning Analytics and Knowledge* (pp. 203–211). New York: ACM.

Wise, A. F., & Schaffer, D. W. (2015). Why theory matters more than ever in the age of big data. *Journal of Learning Analytics*, *2*(2), 5–13. https://doi.org/10.18608/jla.2015.22.2

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010). Evidence for a collective intelligence factor in the performance of human groups. *Science, 330*(6004), 686–688. https://doi.org/10.1126/science.1193147

Xie, K., Miller, N. C., & Allison, J. R. (2013). Toward a social conflict evolution model: Examining the adverse power of conflictual social interaction in online learning. *Computers and Education, 63*, 404–415. https://doi.org/10.1016/j.compedu.2013.01.003

Xiong, R., & Donath, J. (1999). PeopleGarden: Creating data portraits for users. In *Proceedings of the 12th Annual ACM Symposium on User Interface Software and Technology* (pp. 37–44). New York: ACM. https://doi.org/10.1145/320719.322581