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Student-centredness in physics laboratory teaching sessions

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A R T I C L E I N F O

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Dialogicity

A B S T R A C T

There is a call for more interactive and student-centred pedagogy in higher education. This also concerns physics laboratory work, where student investigations are too often passive repetitions of close-ended tasks with little guidance from teaching assistants. To address this gap, a laboratory course was designed to enhance active student participation and interaction between students and teaching assistants. A seminal part of the course was the whole-class teaching sessions within which students had the opportunity to reflect on and orientate towards experimental work. Whole-class teaching sessions of four physics laboratory teaching assistants were carefully explored to determine how student-centredness was apparent during these sessions. Particular attention was given to the interactions and communication between teacher assistants and students. The results revealed different ways in which student-centredness can be facilitated in physics laboratory settings through communication, including dialogic elements. These elements consisted of eliciting students' ideas and explicitly linking their experiences to the discussions. Teacher assistants with a pedagogical background implemented dialogic communicative approaches when orchestrating instructional dialogue and linking different activities. Implications for teacher assistant training are discussed.

1. Introduction

Recently, there has been a call to shift from closed 'cookbook'-style physics laboratories (labs) to including some open-ended elements (Smith & Holmes, 2021). Although they may have their place for example in more technical and hands-on training, following detailed steps in a lab task aligns with passively listening to a lecture. Lab work should involve students in designing investigations, formulating explanations, developing models, and expressing and justifying their ideas. This kind of activity is more interactive and situated by nature, enabling students to perceive the value and meaning of the tasks they perform (Sadler, 2009). Although its benefits have been acknowledged (Wong & Chapman, 2022), the research on interaction and interactive pedagogy in higher education (HE) is

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still an under-researched area. In HE, TAs play a crucial role in acting as a bridge between students and university teachers. Generally, the interaction between students and TAs needs to be investigated from various dimensions, including e.g., their roles, responsibilities, and the nature of their relationship. TAs are typically undergraduate or graduate students who assist with teaching and who may face multiple challenges in their roles (Riese et al., 2021). Even though the smaller competence gap between the TA and the students can benefit both learning and motivation (Dawson et al., 2014) and many TAs plan to continue their academic careers (Lin et al., 2013; Miller et al., 2018), they often have limited or even non-existent educational training (Luft et al., 2004) which can cause issues during, for example, assessment of student learning (Wald & Harland, 2020). Subject departments' often offer TA training courses that might focus simply on classroom management or pedagogical content knowledge (Hammrich, 2001; Hollar et al., 2000). There is a need to develop TA training as these programs often result in inconsistent learning experiences and thus in a lower quality of teaching for the students (Hughes & Ellefson, 2013). TAs' responsibilities in science subjects often lie in guiding lab work and/or recitations. In the department where this study takes place, TAs have been used to supervise lab work for many decades because it offers the TAs opportunities to gain teaching experience and is also financially sustainable for the department. Recently, the lab courses at the department were renewed to include also whole-class teaching and not simply supervision of student experimental work. Whole-class teaching session refers to an instructional activity which is orchestrated by the teacher with possibility for all students to participate in and elaborate on. These TA-orchestrated sessions offered a forum for students to reflect and orient towards forthcoming lab work, which also enables research on how interactions take place in renewed settings.

This study applies theoretical frameworks that address instruction and interaction to HE (see studies in primary and secondary contexts, e.g. Hennessy et al., 2020). Especially exploration of TA and student interaction is still needed in order to understand the nature of communicative approaches taking place in this setting (Mortimer & Scott, 2003). One challenge for HE is how theoretical perspectives and derived methodological approaches fit in teaching and learning subjects such as physics. For this purpose, frameworks of pedagogical link-making (Scott et al., 2011) and communicative approach (Mortimer & Scott, 2003) are applied in studying the interactions in a physics lab course. These frameworks originate from sociocultural theory (Vygotsky, 1978), which highlights the importance of interaction. Sociocultural perspectives of teaching and learning emphasise that learners acquire new strategies and knowledge as they discuss topics among the whole class and in peer interactions (Littleton & Howe, 2009). Especially whole-class discussion has been shown to lack in the communicational spectrum, while being dominated by lecturing and transmission modes of teaching (Myhill, 2006). The prevailing forms of communication could be challenged through questioning strategies that stimulate idea sharing (Mortimer & Scott, 2003) or productive thinking facilitating student reasoning and argumentation skills (Chin, 2007). In this study whole-class lessons cover common class-sizes in Finnish education (Lehesvuori et al., 2013) with exclusion of mass lectures.

Studies that have delved into university physics student interactions, for example, the way physics students interact in groups when engaging in inquiry tasks (Lämsä et al., 2018), have been more focused on macroscale temporal scrutiny of the changes in collaboration activities. The extensive work around more student-centred approaches such as inquiry and problem-solving strategies in groups has been rationalised by so-called 21st century skills (Berge & Danielsson, 2013). The current reform of physics labs calls for an emphasis on developing experimental skills (Walsh et al., 2022) and the inclusion of open-ended elements to increase student agency (Kalender et al., 2021).

1.1. *Student-centredness in science education*

Lecturing has been recognised as a traditional teacher-centred method, especially in HE (Marmah, 2014), and teachers have been quite reluctant to shift towards more interactive pedagogy (Chadha, 2020; Plush & Kehrwald, 2014). Traditional transmission modes of teaching have been criticised for limiting learners' opportunities to share their everyday conceptions (e.g., Lehesvuori et al., 2018; Driver et al., 1994; Lemke, 1990), and yet they continue to dominate science subjects (Chadha, 2020; Mercer et al., 2009; Wells & Arauz, 2006). Despite the need for teacher control and support when navigating learners in and through science, the overuse of teacher-centred and authoritative approaches may result in learners losing interest in science (Lyons, 2006). There is evidence that student-centred approaches within teacher-orchestrated classroom interactions lead to improved motivation towards learning science (Kiemer et al., 2015).

University students can struggle with their self-conceptions and identity, especially in the beginning of their studies and subjects like physics (Irving & Sayre, 2013). In order to integrate students as active agents in their study field, student-centred approaches that initiate student participation through talking and 'making' science should be practiced (Peters, 2010). This could foster the formation of a self-concept as a scientist and further integration into the community (Jansen et al., 2015). Letting students engage in decision-making in the lab via open-ended elements results in more expert-like beliefs about experimental physics (Wilcox & Lewandowski, 2016) and in an increase in student agency during the lab course (Kalender et al., 2021). Inquiry-based teaching and learning have been linked to student-centredness (Anderson, 2007); however, merely doing closed-ended experiments cannot be counted as scientific inquiry (Smith & Holmes, 2021). Instead, if inquiry is integrated with authentic reasoning and argumentation (Lehesvuori et al., 2017), the conditions for establishing student-centredness are made possible through dialogue (Wells, 1999). Little is known about how these aspects are discussed in HE and science instructional labs, especially with TAs. Stang and Roll (2014) found that the number of interactions that TAs had with students in the lab was positively associated with students' engagement in the lab. Their study did not elucidate the types of communication associated with these interactions. Wan et al. (2020) characterised the interaction patterns of TAs in a physics instructional lab setting into three profiles: the group-work facilitators, the waiters, and the whole-class facilitators.

1.1.1. *Different forms of student-centredness*

Student-centred approaches have also been highlighted in educational policies (MoE, 2008), curricula (REMOVED FOR REVIEW), and university strategies (REMOVED FOR REVIEW). Student-centredness can be carried out in instructional approaches (Lehesvuori & Ametller, 2021) through shared responsibility and ownership (Lehesvuori & Ametller, 2021; Enghag et al., 2007) or self-directed learning (Schweder & Raufelder, 2022). Based on the literature and our previous studies, some of the presented dimensions formulated in the context of this study are as follows:

- *Instructional settings and approaches:* Student-centredness can be facilitated through activities that support peer interaction and group discussions, and, in general, interactions within students can express themselves during exploration and inquiry of ideas (Wells, 1999).
- *Shared responsibility:* Student-centredness manifests in shared responsibility, which means that students have freedom of choice to material, methods, and content.
- *Shared ownership:* This can be conveyed through explicit notification of students' views and efforts (Enghag et al., 2007). That is, students' role as makers, and not only as re-creators, of science is acknowledged. Shared ownership can manifest, for example, in pedagogical links that enhance continuity and emotional engagement (Lehesvuori & Ametller, 2021; Scott et al., 2011).
- *Communication:* Students are given space to express their thoughts without fear of being wrong, and these are also explicitly taken into account. Students have possibilities for authentic reasoning and argumentation, which is often facilitated through a dialogic communicative approach (Mortimer & Scott, 2003).

Whereas this study addresses communication more on surface-level rather than providing information beyond behavioural engagement, it has been shown that especially problem-solving group discussions are potential for cognitive engagement enhancing learning (Tullis & Goldstone, 2020). And, although peer interaction is fundamentally discussed as influential especially with challenging tasks, it does not diminish the teacher's role in orchestrating post-peer-discussions and conclusions in whole-class discussions (Lehesvuori & Ametller, 2021).

1.2. Pedagogical link-making and communicative approach

Pedagogical link-making addresses the ways in which teachers and students make links between ideas and science concepts within instructional dialogue. Pedagogical link-making encompasses, not only how science content is discussed (Lehesvuori & Ametller, 2021; Scott et al., 2011), but also the ways students are emotionally engaged in learning processes through linking their experiences and ideas to knowledge building (Barreto et al., 2021). In relation to both knowledge building and emotional engagement, different ideas and experiences are linked in time through facilitation of continuity (cf. Jakobson & Axelsson, 2017). The expected interplay between viewpoints of teacher and students can be seen as the driving force for more dialogic communication. Different forms of link-making have been shown to also correlate with physics learning. That is, the way physics concepts are linked in their temporal surroundings (Schlotterbeck et al., 2020) as well as between contexts (Viiri & Helaakoski, 2014) makes a difference. Concerning this study, striking the balance between introducing scientific content and considering student views takes place through pedagogical link-making and

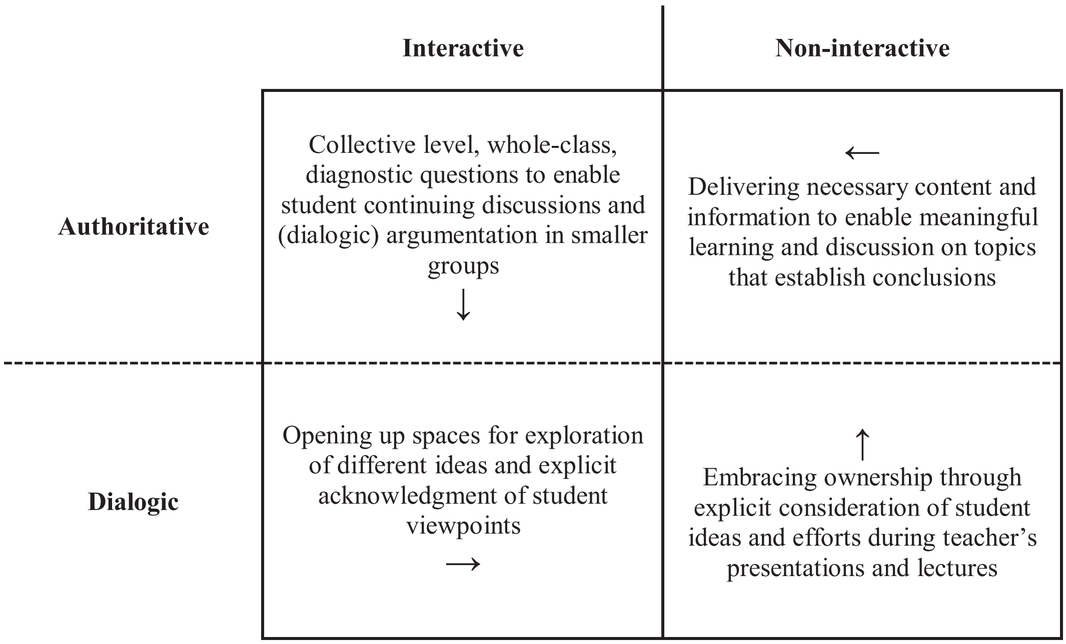

Fig. 1. Quadrant about how student-centredness can be facilitated through communicative approaches.

facilitation of different communicative approaches (Mortimer & Scott, 2003).

Mortimer and Scott's (2003) framework for Communicative approaches differentiates the typical transmission modes of teaching from more student-centred approaches conveyed through more interactive forms of communication and instructional dialogue (Lehesvuori et al., 2018). The framework also enables understanding what counts for meaningful learning science (Scott & Ametller, 2007). The framework consists of four categories generated from a combination of two dimensions: interactive/non-interactive and authoritative/dialogic. Interactive talk allows students to participate, whereas non-interactive talk is of a lecture type, and whereas the dialogic approach takes account of diverging ideas, the authoritative approach focuses on a specific point of view, usually the scientific view, controlled by the teacher. Although dialogicity can be a shortcut to student-centredness (Lehesvuori et al., 2018), in light of the presented literature, we derive a quadrant introducing examples of how student-centredness can be reached in all four communicative approaches (see Fig. 1). In terms of meaningful learning of science (Scott & Ametller, 2007), it can be argued that all four communicative approaches play a role in student-centredness when the aim is to learn science. Complementing Fig. 1, the communicative approaches and examples of their relation to student-centredness:

- In the question-answer routine of the authoritative and interactive approach, students' responses are often evaluated, and the teacher neglects diverging ideas. The authoritative approach focuses on scientific points. Student-centredness can be present, for example, in diagnostic questions, which can be exploited in group discussions within students to justify and reason their selections. Thus, the interactive authoritative communicative approach could lead to potential, even dialogic, argumentation (Author et al., 2017).
- The dialogic and interactive approach explores students' ideas (e.g., everyday views) but has no evaluative aspect. In Mortimer and Scott's (2003) categorisation, the dialogic approach is considered when the teacher is not trying to achieve a specific point. Rather, the teacher attempts to elicit the students' points and works with contrasting views. This aligns with student-centredness by providing spaces for different ideas.
- In the dialogic and non-interactive approaches, the teacher focuses on contrasting points, such as students' everyday views, and moves on to present the scientific view. Even though the teacher lectures, diverging ideas are discussed (note: dialogic nature). Although this is the most infrequent communicative approach (Lehesvuori et al., 2013), it has major potential to embrace shared ownership, as the teacher explicitly considers student efforts and ideas. This can be essential when building links between pre-conceptions and to-be-learned content.
- In the authoritative and non-interactive approach, the teacher presents scientific content by lecturing and takes no account of contrasting points of view. Although often linked to teacher-centredness when overused, the teacher's lectures and presentations correspond to meaningful learning of science in terms of providing students with the necessary knowledge to pursue their individual and group work.

The division between different approaches should not be seen as dichotomous (Scott et al., 2006); rather, approaches seed each other in a cyclic continuum (Lehesvuori et al., 2013). As suggested by Scott and Ametller (2007), after scientific content has been introduced via authoritative approaches, students should be given opportunities to adopt this content in their discussions and talk. Conversely, if students' ideas have been collected with low interanimation of these ideas, then these ideas should be linked to scientific ones via more authoritative approaches led by the teacher as a part of knowledge building processes. An example of a teaching strategy integrating different teacher-orchestrated instructional activities and communicative approaches could include the following phases and shifts between them: 1) delivering necessary information to set up the lesson (authoritative and non-interactive); 2) collecting student ideas and/or pre-conceptions (authoritative and interactive); 3) using collected information to set up dialogic discussions and argumentation (dialogic and interactive); 4) taking explicitly into account student ideas when building links between students' and science's points of view (dialogic and non-interactive); and 5) establishing scientific conclusions (authoritative and non-interactive). The order may vary; for example, the lesson may begin by opening dialogic space when mapping students' everyday views.

This study adapts the framework to interpret the instructional activities and interactions taking place in lab course whole-class teaching sessions. The framework offers a straightforward approach to exploring whether student-centredness is taking place in interactions and especially communications orchestrated by the lab TAs. Although authoritative approaches typically dominate teacher-orchestrated communication, any instances of implementing the dialogic approach could serve student-centredness in temporal surroundings across and through links between communicative approaches (Lehesvuori et al., 2013).

1.3. Research questions

The study aims to determine how different forms of student-centredness manifest in physics lab whole-class teaching sessions. In particular, the role of communication is explored through the following research questions:

How do TAs enable student-centredness through:

a. different forms of pedagogical link-making?
b. different forms of instructional dialogue?

The findings of this study will provide new information about how physics lab TAs enhance student-centredness in a renewed physics lab context when orchestrating whole-class teaching activities and communication. Furthermore, the implications for TA training are discussed.

2. Methods

2.1. The context and the participants

A reformed first-year physics lab course was developed in <REMOVED FOR REVIEW>. The participant students ($N = 70$, see Table 2) are mostly physics majors, although sometimes also chemistry, mathematics and other STEM related majors may take the course. The course includes no lectures and no self-study material. The plan was to engage students in more active learning involving them in designing measurements, peer discussions, and iteration of the technology-enhanced investigations. Previously, the course included students' doing experiments and measurements in lab settings under the supervision of a TA. This supervision was related to technical support and to checking that measurements had been made and that the results were suitable for analysis. The students were expected to mostly self-study the necessary content and skills for the often verification-based lab tasks. The reformed course focuses on developing students' experimental skills with open-ended elements in each task, instead of covering the content of the lecture courses. The course has fixed weekly four-hour lab sessions with TAs, who now have more responsibility for teaching the necessary content and experimental skills, as well as guiding the students through the experiments and measurements. TAs' duties consist of teaching the weekly sessions, grading and giving written feedback to the documents returned by the students (e.g., presentations and brief lab reports) and participation to the weekly reflection and planning meeting with faculty members. Concerning this study, in particular, TAs participated a planning meeting a week before where everyone was walked through the session contents, and the TAs received ready-made slides to build their teaching around.

In the one-hour pre-experimental phase, the TAs familiarise the students with the experiment they are about to conduct. Further, the necessary content related to, for example, error analysis is presented in this phase. The two-hour experimental phase involves the design and performance of the actual measurements. The one-hour post-experimental phase is reserved for data analysis and reporting of the results. Despite the presented structure, there is flexibility for students to pace their investigations. The TA-orchestrated whole-class pre- and post-experimental phases are expected to play a specific role in both practical orientation and deeper reflection on the explored phenomena (Rollnick et al., 2001). Furthermore, in this format, there is potentially more student–teacher interaction involved, which necessitates considering pedagogical approaches when orchestrating activities, as well as educational dialogues. Compared to previous models (cf. Koskinen et al., 2018), student ownership of learning and possibilities for the adaptability of the time and place are decreased (cf. Enghag et al., 2007), as student-centredness is conveyed through versatile onsite communication (Lehesvuori et al., 2018).

The information in Table 1 for background information was collected through personal interviews with the assistants (second Author). TAs were asked about their previous background as TAs, their participation in TA courses, and their personal motivation to be TAs. All names presented in the article are pseudonyms. In <COUNTRY REMOVED> TAs have usually finished their bachelor's degree and are continuing in their master's degree studies (see Table 1). Another group that often serves as a TA is PhD students (see Table 1). Master's level TAs are paid by the hour and PhD level TAs teach as a part of their PhD researcher contract. Although TAs may not have taken part in pedagogical studies, some departments organise TA training. TA training is important for university-level science teaching overall, since many TAs are aiming towards academic careers (Lin et al., 2013).

Whereas the Table 1 provides the background information of the TAs, the main data consisted of video-recorded whole-class teaching sessions of four TAs (1 session per TA) preluding measurements. Five TAs assigned for this study, yet one TA was unable to keep his video recorded session. The focus in the lab session analysed was on comparing and pooling measurements together, finding outliers, and developing the measurement setup. This session was chosen because it potentially included whole-class teaching connected to the previous week's lab work, in which students used their mobile phone acceleration sensors to measure a certain distance in steps and metres. The data from the previous lab sessions were collected and compiled to be used for the whole-class teaching session, including discussion, tasks about errors, outliers, etc. Thus, the setting enabled student-centredness, as the students' measurements were the starting point for the teaching and group discussion tasks.

Table 1
Background information about the physics laboratory teaching assistants.

Information	John	Mary	Shelly	Dora
Study status	1st year PhD student	Master's degree student, finalising master's thesis	2nd year PhD-student	1st year PhD student
Course for assistants and/or other pedagogical studies	No course for assistants. No pedagogical studies	No course for the assistants. No pedagogical studies	No course for the assistants. Ongoing pedagogical studies for adult education	Course for assistants. Basic education studies. Discontinued subject teacher education studies. Applying for an Adult Education degree
Experience as teacher and/or assistant	Spring of 2019, as a laboratory assistant of physics basic studies	Spring of 2019 to autumn of 2021, as a laboratory assistant of physics basic studies	Since autumn of 2019 to autumn of 2022 (excluding COVID-19 lockdown), in basic and intermediate studies	Since spring of 2020 (exclude COVID -19 lockdown) to autumn of 2022, in basics and intermediate studies and accelerator laboratory
Personal motivation for assistant/ teaching work	A colleague asked for interest	Positive experiences about laboratory work as a student and likes ‘teaching kind’ of duties	An email requested interest and positive experience of peers	The salary and positive experiences of peers

2.2. Data collection

Four video-recorded whole-class teaching sessions on the same topic were explored. The length of each session was approximately 45 min. The video recording was organised for sufficient collection of relevant data while minimally disturbing the execution of the whole-class teaching sessions. The camera was placed by the researcher before the teaching session began. The wide-angle camera captured both the teacher and the students. Whereas this study does not discuss the impact of videoing, prior research on video-based studies suggests that videoing have minimal to no effect on the behaviour of both teachers and students (Fischer et al., 2014). Video data was collected on-site by the first Author. He is not personnel of the Department of Physics, rather his role is in bringing pedagogical insights to further development of the course influenced and designed by the other Authors. The organisation of the data-collection could be seen as a traditional researcher-participant setting within which researcher merely observes and places no input to execution of the lesson. It has been shown that this kind of setting unlikely effects on the verbal behaviour of the participants (Samph, 1976).

TAs and students were asked for their consent to take part in the study. The TAs filled in a written consent form, and students were informed about the research at the beginning of the semester, when digital consent forms were collected. In addition, the students were informed about the study at the beginning of the video recording, and they were given the opportunity to withdraw from being seen in the recording at any point of the study. The lab TAs were only informed about the general aims of the research beforehand as required in the study's ethical guidelines.

2.3. Data analysis

The analysis was conducted at different levels. At the macro level, the lessons were divided into episodes. During this process, the following types of instructional activities were detected alongside paying attention to communicative approaches:

- Teacher presentation (TP): The TA presents the content and/or provides instructions for the task. The prevailing communicative approach is authoritative and non-interactive. The approach may include short exchanges and passages of interactive communicative approaches (Lehesvuori et al., 2019).
- Group discussion (GD): Students discuss a task together. The type of student–student discussion is not the focus of this study (cf. Díez-Palomar et al., 2021). Also, the framework of communicative approach is originally developed for exploring teacher-student interaction.
- Instructional dialogue (ID): The TA orchestrates interactive teacher–student interactions. Instructional dialogue can be facilitated through dialogic communicative approaches, yet there is also a place for authoritative approaches in the meaningful learning of science (Scott et al., 2006).

The preliminary division into episodes was conducted in real time during the data collection. The final division into episodes was then conducted from the videos. The end of an episode can be marked by changes in activity, topic, or communication, hence at the same time signalling the beginning of the next episode. Changes in spoken language could indicate these episodic shifts, and can be often detected by contextual cues such as pauses, changes in intonation, hesitation, and linguistic marks (Polman, 2004). The codes for the instructional activities were very distinct.

The structure of the lessons and codes for the episodes were discussed and confirmed by the first and second authors. First author did the initial coding in lesson notes during video recording and confirmed the structure episode by episode through the videos. The structure was then checked by the second author who prepared the reflective sessions. The examples were selected by the first and second authors, who familiarised themselves with both lesson notes and video recordings.

After categorising the instructional activities at episode-level, a more in-depth and microscale analysis of the interactions was conducted for the selected episodes. The selection of the cases was made based on the differences found in the implementation of the communicative approaches (see Fig. 1). The selection followed a purposeful selection procedure, aiming to bring forth the phenomena under exploration (Patton, 2015). The approach followed a strategy for presenting counter-examples across cases (Yin, 1994). The

Table 2
Types of instructional activities (TP = teacher presentation; GD = group discussion; ID = instructional dialogue; N/A = not applicable/applied; E = example).

Episode	John	Mary	Shelly	Dora
	17 students	15 students	21 students	17 students
1. Introduction to the day's topic and assigning task A based on student measurements	TP	TP	TP	ID (E1b) + TP
2. Task A: Group discussion	GD	GD (E2a)	GD	GD
3. Collecting ideas	(N/A)	(N/A)	ID (E2b)	ID (E2c)
4. Presentation and assigning Task B	TP (E1a)	TP	TP	TP
5. Task B: Group discussion	GD	GD	GD	GD
6. Presentation and assigning Task C	TP	TP	TP	TP
7. Task C: Group discussion	GD	GD	GD	GD
8. Instructions for experimental work	TP (after which student experimental work and improved measurements using Task C outcomes)			

selected episodes and rationales for selection are presented and organised under two main theory- and research-guided themes: pedagogical link-making and communicative approach.

The selection of the examples was straightforward, as pre-designed presentation material led to a clear structure for the teaching sessions and differences manifesting merely at the communication level (Sawyer, 2004). As noted earlier, the targeted focus on whole-class teaching sessions is also rationalised by the detectable differences in the often-narrow communication spectrum (Myhill, 2006). The chronological order of the episodes is presented in Table 2. Whereas the presentation of second theme examples follows a chronological order, the examples of the first theme show a mixed order in terms of foregrounding and highlighting the case (see findings).

The in-depth scrutiny of the instructional dialogues (and teacher presentation in John's case) draws on the general principles of sociocultural discourse analysis, complemented by conversation analysis techniques. The sociocultural approach to analysis is less focused on content of language itself and more on the functions that language serves in joint activities and discussions (Mercer, 2004). The conversational analysis techniques, instead, provide ways to access data-emerging patterns (Hsu et al., 2009) or single turns, such as teacher questions and follow-ups (Berland & Hammer, 2012; Chin, 2007), with complementary attention given to multimodal features (Kääntä, 2015). By drawing on student-centredness, pedagogical link-making and dialogic communication, specific attention will be given to any characteristics supporting these aspects to take place (e.g., TA posing open questions and exploring student ideas, see descriptions in Fig. 1). Microscale analysis and interpretation of the selected examples were discussed among all of the authors. In every phase, disagreements were discussed until a consensus was established. Overall, the procedure followed guidelines set for explorative case studies (Yin, 1994) and researcher triangulation (Miles & Huberman, 1994).

3. Findings

The Table 2 reveals that the structure of the joint session followed a similar pattern in all cases. Teacher presentation of the content was followed by tasks engaging students in group discussions based on Tasks A, B, and C. The group discussions were followed by further presentations and instructions for the next steps. Exceptions in the presence of instructional dialogue were, however, detected in Shelly's and Dora's sessions. Whereas only Dora successfully challenged the prevailing authoritativeness and applied instructional dialogue at the beginning of the session when reviewing students' experiences from their previous efforts in experiments and data collection, Shelly and Dora built an episode-level communication link between the group discussions and teacher presentations. In other words, some ideas arising from the group discussions were brought to the social plane of the whole class, which was not the case in John's and Mary's teaching sessions.

The episode-level overview provided in Table 2 indicates that student-centredness was facilitated through opportunities for peers to share their ideas on pre-designed tasks. This corresponds with facilitating student-centredness in instructional approaches through group discussions. Although the instructional design—that is, the prepared material and activities—also included consideration of students' previous measurements, there was some shared ownership of the content. These ideas were used in the discussion and further development of the methods for continuing measurements, which also conformed to fostering pedagogical link-making and continuity. Although student-centredness was conveyed in the design of instructional approaches and shared ownership, further exploration is needed to understand how student-centredness took place in teacher-orchestrated communications. Thus, the selected cases are explored next in order to address how student ideas were linked and brought to instruction through both aspects of communication—authoritative and dialogic.

3.1. *Pedagogical link-making and different ways to extend the context*

The first set of examples concern pedagogical link-making, addressing different ways to extend the context:

- **Example 1a (E1a)** is about John's presentation about the consideration of errors in measurements. Distinct communication moments involve the lab TA linking his own experience about measurement errors in his own PhD study to the students' measurement task. Although the example highlights the lab TA's ownership of the content as well as his experiences, this form of pedagogical link-making was the only one of its kind in this dataset and could serve as an indicator for meaningful interactions.
- **Example 1b** complements E1a as a counter-example. Dora's beginning of the teaching session included a brief moment of instructional dialogue and a dialogic communicative approach implemented before the teacher's presentation. The purpose was to link the students' previous experiences to the day's activities. This corresponds to linking for continuity and shared ownership.

The first example (E1a) involves John presenting the factors that can influence the measurements and cause errors. John's presentation of the prepared content is interrupted by himself as he brings up some real-life experiences about measuring:

Used transcription markers: [text] = talks over, right after or simultaneously, [x] = wait time × seconds, [text] = clarification or additional necessary information, (…) = cut-off or reformulated sentence

John	So here we have some outliers. And, these outliers might have an effect on the depicted values. For example, it greatly affects the mean value. Those really outlying results. One reason could be that there is something wrong with the measurement devices [reads from the slides]. The other one is that the heating or cooling of the measurement device has not been stabilised. This is very common, and in fact, it happened to me yesterday [change of tone]. I was doing neutron measurements in <PLACE REMOVED FOR REVIEW>, and we were measuring the Californium-252 source using different distances. We used a gas-filled helium-3 neutron detector. Every time we changed the distance, the counting frequency increased or decreased. Then, we noticed that

(continued on next page)

(*continued*)

	every time we changed the distance, it took several minutes to get the results stabilised. So, we did have to wait until the results were stabilised for the exact dose rate. Or the counting frequency. After that only could you record the results. It was noticed that with lower dose rates, it took more time to stabilise. So this can be a very common reason [points to the slide]. You just had to be calm and wait for the stabilisation and only then record the results. So this happened yesterday when I visited <PLACE REMOVED FOR REVIEW >. And then the documentation can be sufficiently conducted [shifts to reading from the slide mode], or there was a pause in measurements. It can be that measurement configurations or geometry can change… [continues teacher presentation].

3.1.1. *Comments and interpretations*

The example begins with a teacher presentation of the pre-prepared content projected to a screen. This direct presentation is interrupted when John links his own experiences of dealing with errors in measurements and the importance of stabilising the measurements. Although this kind of link-making could support both motivation and learning (Viiri & Helaakoski, 2014), it is an opposite to shared ownership of knowledge, which was highlighted as one of the student-centred approaches. Although this demonstrates John's mastery of the content, it also underlines the asymmetry between the students and the TA. One option to bring in student experiences in terms of shared ownership could have been at the beginning of the lesson through explicit recognition of previous measurements. Besides shared ownership, this facilitates link-making for continuity (Scott et al., 2011). This is demonstrated in Dora's initiation (E1b) of the teaching sequence, in which she asks about student experiences from the previous measurement session during which she was absent:

1	Dora	So, you were doing measurements with the substitute teacher. How did it go? What kinds of results did you obtain? How do you feel about last week's sessions? [4]
2	Student1	Well, some things were a bit overwhelming and other things were a bit clearer. I'm not sure whether it is one of the purposes of today to get a clearer picture of the entity?
3	Dora	Yeah, sure it is. What else?
4	Student2	Yeah, it was clear when it was the peaks that were used to get the step-count. But when using Excel to get something sensible out, then it was a bit more messy.
5	Dora	Okay. Yeah. It might become clearer today since the aim is to develop the methods a bit further…

Whereas another example (E2c) from Dora later explores dialogicity, this example complements the above interpretations of shared ownership through opening up space for students' voice and linking their previous experiences and knowledge to the to-be-taught content. Drawing on communicative approaches, John's presentation followed the authoritative and non-interactive communicative approaches, which are demonstrated by teachers focused on lecturing and content. Dora's counter-example demonstrated elements of the dialogic communicative approach, such as collecting ideas and experiences (turn 1), probing feedback (Scott et al., 2006) and wait time (Lehesvuori & Ametller, 2021) (turns 1 and 3). Although the episode is dominated by the subsequent teacher's presentation and authoritative non-interactive approach, the beginning of the teaching sequence supports the theme of linking for continuity and emotional engagement (Scott et al., 2011).

3.2. *Facilitating student-centredness through instructional dialogue*

The second set of examples address how instructional dialogue can support student-centredness through different communicative approaches (see Fig. 1) when connecting two instructional activities:

- **Example 2a** illustrates Mary's shift between two instructional activities without implementing instructional dialogue. Examples 2b and 2c are presented as counter-examples of how instructional dialogue is implemented between group discussion and teacher presentation.
- In **Example 2b**, Shelly poses an open question, which she then reformulates to a diagnostic one. This is one of three (see examples 1b and 2c) instances in which a space opens up for dialogue and for students to express their experiences. Although it does not lead to dialogic discussions, the example demonstrates how an interactive and authoritative communicative approach could potentially foreground follow-up dialogues and activities. Accordingly, Example 2c complements by illustrating the implementation of the dialogic approach.
- In **Example 2c**, Dora opens up space for dialogic discussions and orchestrates this by implementing a dialogic approach. This example demonstrates the bridging of communication between two activities: group discussion and teacher presentation.

All these examples (E2a, E2b, and E2c) take place after the student group discussion. The task for the group discussion was to investigate and discuss two graphs that were formed based on the students' measurements conducted the week before. Based on group discussions, students should make notes on observations, explanations, and conclusions. The first example (E2a) concerns Mary's shift from group discussion to presenting the content from the slides:

Mary	Ok, now let's move on [walks to screen]. (2) So, let's have a look at when the measurements can be compared and when they cannot [continues with teacher presentation].

In Mary's case the shift in activity, as well as in episode (see Table 2 for Episodes 2 and 4), was evident in her verbal cue 'Ok, now let's move on' complemented with a proxemic shift (Scott et al., 2006). In the following examples (E2b and E2c), this shift takes place in an entire episode (see Table 2 for Episode 3), which is characterised by interactive communicative approaches. Unlike Mary's verbal cue, Shelly starts a new activity by posing a question after checking with the groups that their discussions and notes are ready:

1	Shelly	Was there a clear distinction between observations and conclusions… no, no (shakes head and reformulates), between explanations and conclusions? That is, was this question about what explains the observations, and what can be concluded based on those? (2) Was it a clear distinction, or did you have to think about it a bit? (3) [No responses] If it was a clear distinction, please raise your hands!
2	Student1	What was the question again?
3	Shelly	The question was that was there a clear distinction between what explains observations and what can be concluded based on those? [now some students raise their hands more confidently] (2) So some of you thought it was clear. If you had to think it through a little, then raise your hands [Shelly raises her hand too demonstratively] (3). Ok, the rest, well, something in between… [Student 2: it was difficult] Yeah, it can be difficult sometimes to differentiate. I would kind of like to hear about your observations, but we do not probably have time for it [peeking her watch on her wrist], but I will come to this later and ask about your observations. So now, let's move on to the next thing: the comparison of measurements.

Shelly begins with a question that she immediately reformulates. After no responses, she repeats the question and finally narrows it down to a diagnostic hand-raising activity. Although some hands were raised, one student asked for clarification. Shelly took this to rephrase the question one more time. While posing the second opinion ('had to think it through'), Shelly demonstrates an uncertain raising of her hand. Although not perhaps intended, this manoeuvre could give the impression of decreased ownership of the subject mastery through demonstrated uncertainty. This could decrease the authorship of the content (Lehesvuori & Ametller, 2021), thus decreasing the asymmetry between the students and her. In the end, although Shelly shows her interest in student efforts, the narrowed diagnostic question posed in the beginning sets the tone for the authoritative and interactive communicative approach being implemented. Despite the low level of interactivity, this still differs from direct movement from group discussions to teacher presentation (cf. John and Mary).

With respect to the above, the next example (E2c) demonstrates higher levels of interactivity and dialogicity. Similar to Shelly, after checking that every group is ready for their discussions, Dora poses a question. The question addresses whether the student measurements discussed can be compared with each other:

1	Dora	So, next we are going to discuss the conditions where the measurements can be compared to each other. Like, are the measurements comparable with each other? For example, in Fig. 1, there was panel A for which the length was indicated as the number of steps. So, what do you think? Can they be compared to each other directly? Like the measured distance? Can we say that you got 60 steps and I got 80, so either one of us has an incorrect measure, or correct? Can we say it like that? Can we make any kind of conclusion?
2	Student1	Well if they are in the same scale then we could probably compare them. But if there is like zero in front of, or like the comma in a different place, then we could say that the other one is wrong.
3	Dora	All right [neutral acknowledgement], yeah. Any other ideas?
4	Student2	Well, I would say that in the context of this task, the accuracy is quite sufficient
5	Dora	All right [neutral acknowledgement]. In what way in relation to this task?
6	Student2	Well, we measure approximately 75 m distance with steps, and we can see that some of those measurements go wrong anyway.
7	Dora	All right [neutral acknowledgement]. (2) Yes [points to a student who wishes to respond].
8	Student3	Well, we were thinking. We looked at the other groups because they can be seen in the Moodle environment. I thought that some did not understand the question. [Dora: 'Okay'] [laughing with the rest of the class] Because there were so big differences [Assistant: 'Yeah']. Like only with common sense, it cannot be like thousands of steps in the distance [Assistant nods and says 'Yeah' when another student interrupts]
9	Student4	It wasn't like that, rather it was hard to read the data that was given in the task when it came to summing up the peaks
10	Student3	Yeah, it was hard to multiply the peaks with two. If it had been presented differently, perhaps there would have not been a thousand in the response. Even though the number of parks would have been a thousand. But I don't know. [Dora listens and says 'Yeah' quietly and neutrally.] That's perhaps why there are quite a lot the same values there…
11	Dora	Okay! [Rising intonation]. That was a good beginning for this day's topic. So let's see it then… [continues on the screen and shifts to teacher presentation mode].

The example includes several reformulations of the question (turn 1). Although there are also elements of narrowing down, the final form of the question ('Can we make any kind of conclusions?') is more about wonderment and invitation and opening up the space for ideas. Dora's persistence finally leads to a student response, which is followed by Dora's neutral acknowledgement (cf. Berland & Hammer, 2012). This is congruent with a neutral probe seeking further ideas, which plays a key role in facilitating extended dialogues (Scott et al., 2006). This is characteristic in all of Dora's follow-up turns throughout the episode (especially turns 3, 5, and 7). Other features supporting the dialogic and interactive communicative approach being implemented are the distribution of talk (four students) and students complementing each other (Students 3 and 4 in turns 9 and 10). Altogether, the low interanimation of ideas indicates the idea-sharing purpose of the activity. Although it is not confirmed here how these ideas will be elaborated upon further during teacher presentation, there is clear communicative consistency in the activities linked with a dialogic and interactive communicative approach. When compared to other cases, along with dialogicity, this example demonstrated the highest level of interactivity.

4. Discussion

Our findings revealed that student-centredness took place in varying forms during whole-class teaching sessions in a physics instructional lab setting. The first set of examples highlighted distinct differences in pedagogical link-making. John's linking to his own experiences underlined the ownership of the content. Similarly, Dora's example illustrates link-making for continuity and emotional engagement (Scott et al., 2011) through explicit consideration of students' previous experiences. Dora's approach also more potentially served the purpose of shared ownership and, thus, student-centredness (Lehesvuori & Ametller, 2021). Although both examples can build on meaningful interactions, in Dora's case, this is supported in a temporal continuum that includes both dialogic and authoritative communicative approaches (Scott & Ametller, 2007).

Another key finding of the study suggests, not only, that student-centredness took place in physics lab setting, but how it was established through dialogic communicative approach. Although it has been found challenging among secondary school physics teachers (Lehesvuori et al., 2011), it can be possible also in HE physics education among TAs with less pedagogical training. However, as highlighted in the second set of examples, there was differences between the cases whether and how dialogicity was enhanced when bridging different instructional activities. The differences in communication were particularly salient between the first task and the second presentation phase. Two of the TAs linked these two phases by collecting the students' ideas. Whereas Shelly posed an open question, she also narrowed the question quickly towards a more diagnostic one. Although the intention and question were the kind that could initiate dialogic discussions, the lack of wait time resulted in the premature termination of this purpose.

The implementation of extended wait times could potentially lead to extended and elaborated student responses (Lehesvuori & Ametller, 2021). As presented via a counter-example, Dora was carrying out more extended dialogue, resulting in dialogic interaction. This was evidenced by her insistent enquiry about student ideas, probing follow-up realised through neutral acknowledgement and established collectively (Author et al., 2022). Whether the dialogic communicative approach was implemented or not, in both cases, there was a bridging of communication between student group discussion and teacher presentation. This is common in classrooms when the teacher orchestrates instructional dialogue (Author et al., 2019). It is essential to provide students with opportunities to share their ideas, not only during group discussions but also in the social plane during whole-class discussions (Myhill, 2006). This provides an opportunity for the groups to challenge each other's ideas, including their own. Regarding the cyclic and continuous nature of the meaningful learning of science, Dora's teaching session demonstrated this most explicitly in shifts between different activities and communicative approaches.

Setting up the future TA training, the background information of the two TAs who implemented a dialogic approach revealed their experiences in pedagogical studies. It has been argued that pedagogical orientation and initial training could increase TAs' professional confidence and shift teaching towards being more student-centred (Smit et al., 2023). In this study, student-centredness was also reached in communication, in addition to instructional activities and shared ownership. Although shared ownership was partly present in the pre-prepared content through consideration of students' previous measurements, the responsibility and ownership were also present in the execution of developed measurements that offered flexibility on how to conduct the experiment. We acknowledge that these instances of ownership do not meet some holistic definitions of ownership (Conley & French, 2014), but they play a role as more micro-level factors of student-centredness when strengthened with appropriate communicative approaches. The selected examples shed light on how student-centredness can take place in an expectedly authoritative science context (Driver et al., 1994) through interactive and dialogic forms of communication. Although infrequent, the clips of dialogic approaches are even more important when it comes to highlighting these issues in TA training contexts.

5. Implications and limitations

This study revealed how different forms of student-centredness can take place in whole-class lab teaching sessions of physics TAs. We found that student-centredness evidently increased alongside the level of dialogicity and interactivity. This was demonstrated especially through the cases underlining the second main theme. We conclude that the pre-structured sessions enabled a more controlled, in-depth scrutiny of communication differences and similarities between cases. As noted earlier, even scripted instructions can be considered creative acts, including improvisational freedom (Sawyer, 2004). Preparation and reflection phases have been argued as an important part of lab and experimental work; thus, it was prominent to focus on this exact part of the course instruction. Although the cases opened up how student-centredness can take place within instructional dialogue, the specific focus on cases and a specific type of instruction can, of course, be seen as a partial limitation. In this light, we also acknowledge the limitation of information about cognitive engagement beyond interpreting the communication.

Although teaching approaches have developed during the past few years through more flexible and digitally enhanced learning environments (Rapanta et al., 2020), there is still a need to enrich communication and interaction in digital, traditional, and hybrid settings, especially regarding teacher-orchestrated teaching sessions (Zhampeiis et al., 2022). Our findings illustrate forms of student-centredness in whole-class teaching sessions and how TAs enable student-centredness. This study implies the importance of the pedagogical training of TAs when they are expected to orchestrate instructional dialogue. However, this cannot be confirmed here as the focus was on the execution of the lessons. Although we acknowledge the limitations of the limited data and case study, as the results show, student-centred practices such as pedagogical link-making and dialogical interaction are possible for TAs instructing lab work. Authentic video examples of teaching, such as discussed in this study, could act as catalysts for pedagogical change if they were used as a part of TA training programs. Video clips showing examples of student-centred practices could be shared in TA training meetings and reflected upon. Similar peer reflection using participants own video data are already in wide use in pre-service teacher education (Lehesvuori & Ametller, 2021).

In the future, it would be interesting to explore scaffolding and feedback techniques that TAs use during the experiment and measurement phases. Methodologically, this study introduced how student-centredness and communication interlace, and the relationship can be considered symbiotic in evaluating the quality of interactions. Whereas the instructional aspect is the most accessible aspect, evaluating how students take on shared responsibility and ownership requires much more effort. Accordingly, preparing instructional activities, such as group discussion activities, seems to be an overused shortcut to facilitate student-centredness (Lehesvuori & Ametller, 2021). Therefore, teacher-orchestrated communication should be stressed as a mediator between activities and viewpoints. That is, giving complete responsibility for content creation to students does not mean that teachers and TAs should not orchestrate the dialogue between viewpoints of scientific knowledge and student views during the process. Although this is challenging, it is possible, as evidenced by our findings.

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Ethics statement

The research followed ethical guidelines set by the <REMOVED FOR REVIEW> National Board on Research Integrity. Ethical considerations have been discussed in the Methods section. No separate approval was needed.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) did not use generative AI and AI-assisted technologies in the writing process in addition to integrated basic features of Microsoft Word.

References

Anderson, R. D. (2007). Inquiry as an organizing theme for science curricula. In S. K. Abell, & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 807–830). Routledge.
Barreto, L. P., Rodrigues, A. A. D., de Oliveira, G. C., et al. (2021). The use of different translation devices to analyze knowledge-building in a university chemistry classroom. *Research in Science Education, 51*, 135–152.
Berge, M., & Danielsson, A. T. (2013). Characterising learning interactions: A study of university students solving physics problems in groups. *Research in Science Education, 43*(3), 1177–1196.
Berland, K. B., & Hammer, D. (2012). Framing for scientific argumentation. *Journal of Research in Science Teaching, 49*(1), 68–94.
Chadha, D. (2020). How do we prepare to teach? Exploring science lecturers' authentic approaches to teaching in higher education. *Research in Science Education, 52*, 635–653.
Chin, C. (2007). Teacher questioning in science classrooms: Approaches that stimulate productive thinking. *Journal of Research in Science Teaching, 44*(6), 815–843.
Conley, D. T., & French, E. M. (2014). Student ownership of learning as a key component of college readiness. *American Behavioral Scientist, 58*(8), 1018–1034.
Dawson, P., van der Meer, J., Skalicky, J., & Cowley, K. (2014). On the effectiveness of supplemental instruction: A systematic review of supplemental instruction and peer-assisted study sessions literature between 2001 and 2010. *Review of Educational Research, 84*(4), 609–639.
Díez-Palomar, J., Chan, M. C. E., Clarke, D., & Padrós, M. (2021). How does dialogical talk promote student learning during small group work? An exploratory study. *Learning, Culture and Social Interaction, 30*(Part A), 100540.
Driver, R., Asoko, H., Leach, J., Mortimer, E., & Scott, P. (1994). Constructing scientific knowledge in the classroom. *Educational Researcher, 23*(7), 5–12.
Enghag, M., Gustafsson, P., & Jonsson, G. (2007). From everyday life experiences to physics understanding occurring in small group work with context rich problems during introductory physics work at university. *Research in Science Education, 37*, 449–467.
Fischer, H. E., Neumann, K., Labudde, P., & Viiri, J. (Eds.).. (2014). *Quality of instruction in physics: Comparing Finland*. Waxmann Verlag: Germany and Switzerland.
Hammrich, P. L. (2001). Preparing graduate teaching assistants to assist biology faculty. *Journal of Science Teacher Education, 12*(1), 67–82.
Hennessy, S., Howe, C., Mercer, N., & Vrikki, M. (2020). Coding classroom dialogue: Methodological considerations for researchers. *Learning, Culture and Social Interaction, 25*, 100404.
Hollar, K., Carlson, V., & Spencer, P. (2000). 1 + 1= 3: Unanticipated benefits of a co-facilitation model for training teaching assistants. *Journal of Graduate Teaching Assistant Development, 7*(3), 173–181.
Hsu, P.-L., Roth, W.-M., & Mazumder, A. (2009). Natural pedagogical conversations in high school students' internship. *Journal of Research in Science Teaching, 46*(5), 481–505.
Hughes, P. W., & Ellefson, M. R. (2013). Inquiry-based training improves teaching effectiveness of biology teaching assistants. *PLoS One, 8*(10), Article e78540.
Irving, P. W., & Sayre, E. C. (2013). Physics identity development: A snapshot of the stages of development of upper-level physics students. *Journal of the Scholarship of Teaching and Learning, 13*(4), 68–84.
Jakobson, B., & Axelsson, M. (2017). Building a web in science instruction: Using multiple resources in a Swedish multilingual middle school class. *Language and Education, 31*(6), 479–494.
Jansen, M., Scherer, R., & Schroeders, U. (2015). Students' self-concept and self-efficacy in the sciences: Differential relations to antecedents and educational outcomes. *Contemporary Educational Psychology, 41*, 13–24.
Kääntä, L. (2015). The multimodal organization of teacher-led classroom interaction. In C. Jenks, & P. Seedhouse (Eds.), *International perspectives on ELT classroom interaction* (pp. 64–83). Palgrave Macmillan.
Kalender, Z. Y., Stump, E., Hubenig, K., & Holmes, N. G. (2021). Restructuring physics labs to cultivate sense of student agency. *Physical Review Physics Education Research, 17*(2), Article 020128.
Kiemer, K., Gröschner, A., Pehmer, A.-K., & Seidel, T. (2015). Effects of a classroom discourse intervention on teachers' practice and students' motivation to learn mathematics and science. *Learning and Instruction, 35*, 94–103.
Koskinen, P., Lämsä, J., Maunuksela, J., Hämäläinen, R., & Viiri, J. (2018). Primetime learning: Collaborative and technology-enhanced studying with genuine teacher presence. *International Journal of STEM Education, 5*(1), 20. Article.
Lämsä, J., Hämäläinen, R., Koskinen, P., & Viiri, J. (2018). Visualising the temporal aspects of collaborative inquiry-based learning processes in technology-enhanced physics learning. *International Journal of Science Education, 40*(14), 1697–1717.
Lehesvuori, S., & Ametller, J. (2021). Exploring coherence and authorship in pedagogical link-making in science. *International Journal of Science Education, 43*(17), 2791–2813.
Lehesvuori, S., Viiri, J., & Rasku-Puttonen, H. (2011). Introducing dialogic teaching to science student teachers. *Journal of Science Teacher Education, 22*(8), 705–727.
Lehesvuori, S., Viiri, J., Rasku-Puttonen, H., Moate, J., & Helaakoski, J. (2013). Visualizing communication structures in science classrooms: Tracing cumulativity in teacher-led whole class discussions. *Journal of Research in Science Teaching, 50*(8), 912–939.

Lehesvuori, S., Hähkiöniemi, M., Jokiranta, K., Nieminen, P., Hiltunen, J., & Viiri, J. (2017). Enhancing dialogic argumentation in mathematics and science. *Studia Paedagogica, 22*(4), 55–76.
Lehesvuori, S., Ramnarain, U., & Viiri, J. (2018). Challenging transmission modes of teaching in science classrooms : Enhancing learner-centredness through dialogicity. *Research in Science Education, 48*(5), 1049–1069.
Lehesvuori, S., Hähkiöniemi, M., Viiri, J., Nieminen, P., Jokiranta, K., & Hiltunen, J. (2019). Teacher orchestration of classroom interaction in science : exploring dialogic and authoritative passages in whole-class discussions. *International Journal of Science Education, 41*(17), 2557–2578.
Lehesvuori, S., Ketonen, L., & Hähkiöniemi, M. (2022). Utilizing informal formative assessment and dialogicity during reflections on educational dialogue in mathematics. *Studia Paedagogica, 27*(2), 55–75.
Lemke, J. L. (1990). *Talking science: Language, learning and values*. Ablex Publishing Company.
Lin, S. Y., Henderson, C., Mamudi, W., Singh, C., & Yerushalmi, E. (2013). Teaching assistants' beliefs regarding example solutions in introductory physics. *Physical Review Physics Education Research, 9*(1), Article 010120.
Littleton, K., & Howe, C. (Eds.). (2009). *Educational dialogues: Understanding and promoting productive interaction*. Routledge.
Luft, J. A., Kurdziel, J. P., Roehrig, G. H., & Turner, J. (2004). Growing a garden without water: Graduate teaching assistants in introductory science laboratories at a doctoral/research university. *Journal of Research in Science Teaching, 41*(3), 211–233.
Lyons, T. (2006). Different countries, same science classes: Students' experiences of school science in their own words. *International Journal of Science Education, 28*(6), 591–613.
Marmah, A. M. (2014). Student's perception about the lecture as a method of teaching in tertiary institutions. Views of students from College of Technology Education, Kumasi (COLTEK). *International Journal of Educational Research, 2*(6), 601–612.
Mercer, N. (2004). Sociocultural discourse analysis: Analysing classroom talk as a social mode of thinking. *International Journal of Applied Linguistics, 1*(2), 137–168.
Mercer, N., Dawes, L., & Staarman, K. (2009). Dialogic teaching in the primary science classroom. *Language and Education, 23*(4), 353–369.
Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis* (2nd ed.). Sage Publications.
Miller, C. L., King, H., & Martin, A. (2018). Graduate teaching assistant pedagogical training: A case study. *Journal of Applied Instructional Design, 7*(1), 35–44.
MoE. (2008). *National curriculum framework*. Eritrea Ministry of Education.
Mortimer, E. F., & Scott, P. (2003). *Meaning making in science classrooms*. Milton Keynes: Open University Press.
Myhill, D. (2006). Talk, talk, talk: Teaching and learning in whole class discourse. *Research Papers in Education, 21*(1), 19–41.
Patton, M. Q. (2015). *Qualitative research and evaluation methods*. Sage Publications.
Peters, E. E. (2010). Shifting to a student-centered science classroom: An exploration of teacher and student changes in perceptions and practices. *Journal of Science Teacher Education, 21*(3), 329–349.
Plush, S. E., & Kehrwald, B. A. (2014). Supporting new academics' use of student centred strategies in traditional university teaching. *Journal of University Teaching & Learning Practice, 11*(1).
Polman, J. L. (2004). Dialogic activity structures for project-based learning environments. *Cognition and Instruction, 22*(4), 431–466.
Rapanta, C., Botturi, L., Goodyear, P., Guàrdia, L., & Koole, M. (2020). Online university teaching during and after the Covid-19 crisis: Refocusing teacher presence and learning activity. *Postdigital Science and Education, 2*, 923–945.
Riese, E., Lorås, M., Ukrop, M., & Effenberger, T. (2021, June). Challenges faced by teaching assistants in computer science education across Europe. In *, 1. Proceedings of the 26th ACM conference on innovation and technology in computer science education* (pp. 547–553).
Rollnick, M., Zwane, S., Staskun, M., Lotz, S., & Green, G. (2001). Improving pre-laboratory preparation of first year university chemistry students. *International Journal of Science Education, 23*(10), 1053–1071.
Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education, 45*(1), 1–42.
Samph, T. (1976). Observer effects on teacher verbal classroom behavior. *Journal of Educational Psychology, 68*(6), 736–741.
Sawyer, R. K. (2004). Creative teaching: Collaborative discussion as disciplined improvisation. *Educational Researcher, 33*(2), 12–20.
Schweder, S., & Raufelder, D. (2022). Students' interest and self-efficacy and the impact of changing learning environments. *Contemporary Educational Psychology*, 70. https://doi.org/10.1016/j.cedpsych.2022.102082
Schlotterbeck, D., Araya, R., Caballero, D., Jimenez, A., Lehesvuori, S., & Viiri, J. (2020). Assessing teacher's discourse effect on students' learning : A keyword centrality approach. In C. Alario-Hoyos, M. J. Rodríguez-Triana, M. Scheffel, I. Arnedillo-Sánchez, & S. M. Dennerlein (Eds.), *EC-TEL 2020 : Addressing global challenges and quality education* (pp. 102–116). Springer. Lecture Notes in Computer Science.
Scott, P., & Ametller, J. (2007). Teaching science in a meaningful way: Striking a balance between 'opening up' and 'closing down' classroom talk. *School Science Review, 88*(324), 77–83.
Scott, P., Mortimer, E., & Ametller, J. (2011). Pedagogical link-making: A fundamental aspect of teaching and learning scientific conceptual knowledge. *Studies in Science Education, 47*(1), 3–36.
Scott, P. H., Mortimer, E. F., & Aguiar, D. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*(3), 605–631.
Smith, E. M., & Holmes, N. G. (2021). Best practice for instructional labs. *Nature Physics, 17*(6), 662–663.
Stang, J. B., & Roll, I. (2014). Interactions between teaching assistants and students boost engagement in physics labs. *Physical Review Special Topics - Physics Education Research, 10*(2), Article 020117.
Tullis, J. G., & Goldstone, R. L. (2020). Why does peer instruction benefit student learning? *Cognitive Research: Principles and Implications, 5*(15). https://doi.org/10.1186/s41235-020-00218-5
Viiri, J., & Helaakoski, J. (2014). Content and content structure of physics lessons and students' learning gains: Comparing Finland, Germany, and Switzerland. In H. E. Fischer, P. Labudde, K. Neumann, & J. Viiri (Eds.), *Quality of instruction in physics: Comparing Finland, Germany, and Switzerland* (pp. 93–110). Münster: Waxmann Verlag.
Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. In M. Cole, V. John-Steiner, & E. Souberman (Eds.). Cambridge MA: Harvard University Press.
Wald, N., & Harland, T. (2020). Rethinking the teaching roles and assessment responsibilities of student teaching assistants. *Journal of Further and Higher Education, 44*(1), 43–53.
Walsh, C., Lewandowski, H. J., & Holmes, N. G. (2022). Skills-focused lab instruction improves critical thinking skills and experimentation views for all students. *Physical Review Physics Education Research, 18*, Article 010128.
Wan, T., Geraets, A. A., Doty, C. M., Saitta, E. K., & Chini, J. J. (2020). Characterizing science graduate teaching assistants' instructional practices in reformed laboratories and tutorials. *International Journal of STEM Education, 7*(1), 1–21.
Wells, G. (1999). *Dialogic enquiry: Towards a sociocultural practice and theory of education*. Cambridge University Press.
Wells, G., & Arauz, R. (2006). Dialogue in the classroom. *Journal of the Learning Sciences, 15*(3), 379–428.
Wilcox, B. R., & Lewandowski, H. J. (2016). Open-ended versus guided laboratory activities: Impact on students' beliefs about experimental physics. *Physical Review Physics Education Research, 12*(2), Article 020132.
Wong, W. H., & Chapman, E. (2022). Student satisfaction and interaction in higher education. *Higher Education*. https://doi.org/10.1007/s10734-022-00874-0
Yin, R. (1994). *Case study research: Design and methods* (2nd ed.). Sage Publishing.
Zhampeiis, K., Assanova, G., Toishybaeva, G., Saparbaeva, A., Orazbaeva, A., & Manapova, G. (2022). Academic lectures: Communicative approaches to interactive lectures in today's classroom. *Journal of Positive School Psychology, 6*(6), 7545–7555.