Intern. J. Comput.-Support. Collab. Learn
https://doi.org/10.1007/s11412-024-09422-7

# Zooming in: The role of nonverbal behavior in sensing the quality of collaborative group engagement

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Received: 4 December 2023 / Accepted: 27 March 2024


**Abstract**
Successful computer-supported collaborative learning (CSCL) relies on collaborative group engagement, a complex construct characterized by multifaceted, dynamic, socio-emotional, and socio-cognitive processes. This paper provides a detailed analysis of collaborative group engagement, with a particular focus on nonverbal behaviors as indicators of high versus low group engagement. Using video observations and a multi-method approach, we examine in detail the relationships between different dimensions of group engagement (i.e., behavioral, social, cognitive, and conceptual-to-consequential engagement) and nonverbal behaviors. Using qualitative case analysis, we also provide a rich examination of selected cases to identify the role that nonverbal behaviors play in high-engagement sequences compared with low-engagement sequences. Our findings shed light on specific nonverbal behaviors, including nodding, laughing, and eye contact, as significant indicators of high versus low collaborative group engagement. Notably, more of these nonverbal behaviors are evident in high-engagement sequences, suggesting mutual reinforcement on each dimension of engagement—with the exception of behavioral engagement, where increased laughing or smiling is evident in low-engagement sequences, but still serves a productive group process. The paper concludes with a discussion and implications of the findings. By demonstrating the role of nonverbal behaviors as important indicators, this work contributes to the understanding of the complex, dynamic, and contextualized nature of collaborative group engagement in CSCL settings.

**Keywords** Quality of collaborative group engagement · Nonverbal behaviors · Group learning processes · Higher education · Multi-method approach · Case analysis · Interaction analysis

## Introduction

Successful performance throughout life, in both educational and professional settings, depends on effective learning—often in groups or professional teams. In higher education, there is a growing emphasis on developing students' collaborative digital skills in preparation for a workplace that is technologically advanced, complex, and interdisciplinary (Care, 2018). These skills include regulating learning while solving complex problems, as well as digital and communication skills (González-Pérez & Ramírez-Montoya,

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2022). To this end, CSCL research and theory adopt a ubiquitous vision of learning that embraces technological developments that fundamentally support learning in authentic learning settings (Hmelo-Silver & Jeong, 2023). A large body of empirical evidence demonstrates that CSCL has positive effects on students' learning, perceptions, and skill development (e.g., Chen et al., 2018).

However, simply using digital tools and group tasks in higher education does not guarantee successful group learning. Effective group processes are critical, but not a given (e.g., Kreijns, et al., 2003). For example, Wilson, et al. (2018) found that students working in learning groups experienced significant challenges, including stress, interpersonal conflict, and unequal distribution of effort. Thus, productive group processes involve both socio-cognitive and socio-emotional process regulation (Järvelä & Hadwin, 2013) and depend on collaborative group engagement: Sinha et al. (2015) consider the quality of collaborative group engagement to be multifaceted, dynamic, contextualized, and shared, and therefore critical to collaborative learning. However, the scholarly understanding of this conceptualization of collaborative group engagement is still limited. For example, new empirical research that explores and specifies each facet of collaborative group engagement in detail in different contexts may be valuable (Sinha et al., 2015; Xing et al., 2022), and it is important to study it using new multi-method approaches, including qualitative in-depth analysis (Rogat et al., 2022), to better understand how it manifests in specific CSCL groups.

An important issue in this context is the nonverbal aspects of group learning (e.g., Schneider et al., 2021). Nonverbal behavior is significant because it can provide insights into critical aspects of collaboration and socioemotional conditions, such as the quality of collaboration (Schneider & Pea, 2014), the emotional states of group members (Behoora & Tucker, 2015), and the interpersonal dynamics among group members (Dunbar & Burgoon, 2005). Furthermore, it is well established in social interaction theories that nonverbal behaviors are part of a dynamic system in social settings (Patterson, 2019), such as learning groups, and that group members require both verbal and nonverbal validation from others to experience social presence (Short et al., 1976). Yet, research on the direct relationship between facets of collaborative group engagement and corresponding nonverbal behaviors is scarce. Our own previous exploratory research, in which we statistically related nonverbal behaviors to dimensions of collaborative group engagement with a small sample of study groups, suggested that nonverbal behaviors such as nodding, smiling, or eye contact may signal high- or low-quality collaborative group engagement (Paneth et al., 2023). However, the question remains as to *how* exactly nonverbal behaviors relate to collaborative group engagement.

In this article, we report new original findings from a laboratory study that examines how nonverbal behaviors are related to *specific dimensions* of collaborative group engagement. Our study addresses the shared, contextualized, dynamic, and multifaceted nature of collaborative group engagement (Sinha et al., 2015) in an authentic context of learning through design (cf. Zahn, 2017) and with a multi-method approach (Paneth, et al. 2023). With this research, we will contribute to CSCL research in two important ways: First, we extend the construct of collaborative group engagement by providing a detailed quantitative analysis of its dimensions with a fine-grained measure, examining which nonverbal behaviors are related to which specific dimensions of collaborative group engagement. Second, we zoom in on selected sequences of group processes and qualitatively examine the "how" of these relationships, or the specific roles that nonverbal behaviors play in the different dimensions of collaborative group engagement.

Thus, the goal of this study is to gain an in-depth understanding of nonverbal behaviors in CSCL settings as indicators of different dimensions of collaborative group engagement, as well as the corresponding functions these nonverbal behaviors serve. In the following

sections, we first provide a theoretical background on collaborative group engagement and nonverbal behaviors in CSCL research. We then report on our multi-method approach, consisting of a comprehensive quantitative analysis of specific dimensions of collaborative group engagement and their relations to nonverbal behaviors, as well as a qualitative case analysis of selected cases of collaborative processes, before presenting the results and discussion.

## Collaborative Group Engagement in CSCL

In CSCL, the shared regulation of learning is a challenge for groups (Järvelä & Hadwin, 2013). A key construct addressing the regulation of social interaction in CSCL research is collaborative group engagement, a multifaceted core group process that mediates the relationship between motivation, effort, and learning success at the group level (Sinha et al., 2015). Engagement in learning is central to regulatory learning processes (Järvelä & Hadwin, 2013), the formation of conceptual understanding (Blumenfeld et al., 2006), and thus academic success (Liu et al., 2022).

There are three aspects of student engagement that need more development in theoretical or empirical details: First, when it comes to defining student engagement, there are no standard descriptions. For example, definitions of student engagement refer to "students' psychological investment in learning in terms of motivational interpretations and goals" (Järvelä et al., 2008, p. 302). Second, as noted by Henrie et al. (2015), few researchers have operationalized student engagement across different dimensions and subconstructs. Those who have operationalized engagement in a nuanced way have mostly found distinctions between behavioral, cognitive, and emotional engagement (Fredricks et al., 2004). Third, comprehensive conceptualizations of *collaborative group* engagement in a CSCL context have emerged only recently—even though effective collaboration is critically dependent on high-quality engagement in collaborative learning activities (Sinha et al., 2015). Owing to this lack of consistency in defining dimensions or subconstructs of student engagement, CSCL research is underway to further explore the construct—particularly in collaborative contexts (e.g., Rogat et al., 2022; Sinha et al., 2015; Xing et al., 2022), and more research is needed to understand engagement in CSCL in detail.

Sinha et al. (2015) conceptualize the quality of collaborative group engagement (QCGE) as shared, multifaceted, dynamic, and contextualized, extending previous conceptualizations of multidimensional engagement (Fredricks et al., 2004). According to Sinha et al. (2015), four different dimensions of QCGE can be distinguished in complex, computer-supported learning environments: *Behavioral engagement (BE)* is defined by on-task persistence and effort invested in the group. Sinha et al. (2015) found that BE is necessary but insufficient for overall engagement: Students may attend to the task without cognitive or consequential engagement (e.g., Engle & Conant, 2002). Individual students who stop participating in group discussions can disrupt productive group learning by missing opportunities to collaborate or by causing the entire group to become disengaged (Van den Bossche et al., 2006). Thus, free riders (Salomon & Globerson, 1989) may reduce the quality of BE. In this context, Schneider et al. (2018) proposed the Partner Dominance Effect: here, reluctant group members tend to avoid conflict and let a dominant group member prevail. This in turn leads to a lower quality of BE—and can also be a sign of low-quality social engagement: *Social engagement (SE)* is defined by the quality of socio-emotional group interactions within learning groups. It includes respectful and responsive group interactions in which the contributions of all members are given equal consideration (Barron, 2003; Rogat & Adams-Wiggins, 2015). Such positive group interactions facilitate shared sense-making (Van den Bossche et al., 2006), also known as common ground or shared understanding (e.g., Dillenbourg et al., 2009) among group members. High-quality SE also refers to conceptualizing the task as a group effort rather than an individual endeavor, thus reflecting group cohesion.

SE facilitates productive group processes for elaborating the other dimensions of engagement: cognitive engagement, by increasing the quality of collaborative task coordination, and BE, by re-engaging group members (Sinha et al., 2015). On the other hand, low-quality SE can, in the worst case, lead to status-related conflict and inequality (Salomon and Globerson 1989). *Cognitive engagement (CE)* defines the collaborative development of understanding, and reflects learners' involvement in monitoring, planning, and evaluating as they work on tasks. Sinha et al. (2015) conceptualize CE in a CSCL context as groups' intentional and conscious use of the affordances provided by the learning environment. Groups that demonstrate high-quality CE use shared regulatory strategies while working on their task (Järvelä & Hadwin, 2013). CE can be facilitated by SE, as group members in high-quality social interactions can be assured of receiving constructive feedback that allows for shared and inclusive discourse (Sinha et al., 2015). *Conceptual-to-consequential engagement (CC),* newly introduced by Sinha et al. (2015), refers to student groups' efforts to solve meaningful problems using disciplinary practices and domain-specific content as conceptual tools. Groups that demonstrate high-quality CC actively justify the solutions they identify after critically discussing and weighing alternative solutions to the common problem they are solving. They connect their ideas to prior knowledge and the context of the larger problem (i.e., the solution to the collaborative task). According to Sinha et al. (2015), high-quality CC may facilitate the development of conceptual understanding in CSCL situations. Sinha et al. (2015) used a video-based observational measure to evaluate engagement in CSCL groups and quantified the quality of engagement on three levels (i.e., 1 = low, 2 = moderate, and 3 = high). They used comparative case analyses to demonstrate how the quality of engagement on one dimension can influence the quality of another dimension. For example, high-quality BE and SE could foster high-quality CE, which could then facilitate CC.

Building on Sinha et al.'s (2015) conceptualization of engagement and drawing on other recent literature, there are several recent works that focus on collaborative group engagement in CSCL. For example, Rogat et al. (2022) delineated groups' disciplinary engagement as another multifaceted group engagement framework specifically for analyzing disciplinary practices in science, technology, engineering, and mathematics (STEM) education. They found that different facets of engagement are positively related, suggesting that these interrelationships support the quality of group engagement. For their part, Xing et al. (2022) synthesized different conceptualizations of engagement for their study of group engagement and developed a learning analytics approach to study the facets of engagement in CSCL and its impact on learning outcomes.

Prior research on engagement in CSCL provides evidence on its impact on *learning outcomes*. For example, Sinha et al. (2015) found that members of a low-engagement student group had lower individual learning gains than members of a high-engagement student group. Xing et al. (2022) found that behavioral and cognitive engagement had a positive effect on group problem-solving performance, while social engagement had a negative effect. Liu et al. (2022) found a combined effect of emotional and cognitive engagement on learning outcomes in massive open online course (MOOC) discussions. In addition, Curşeu et al. (2020) found that group learning engagement mediated the effect of group identification on group performance. Recent approaches to automated analysis of group engagement, in which student groups received timely feedback on their group engagement, are also promising in terms of learning outcomes. For example, Zheng et al. (2023) found in their study that student groups that learned with an automated group engagement analysis and feedback tool showed higher group engagement, as well as higher group performance, socially shared regulation, and collaborative knowledge building, than student groups that learned with a traditional online group learning approach.

In summary, collaborative group engagement in CSCL is conceptualized within some slightly different but also overlapping frameworks as socially shared, multidimensional,

dynamic, and contextualized, and has an important impact on learning outcomes. Moreover, in this conceptualization, collaborative group engagement is not a fixed state, but can fluctuate dynamically throughout group collaboration. Consequently, there are not either successful or unsuccessful groups, but rather high- or low-engagement process phases in collaborative learning that can (and sometimes must) be regulated. Despite the growing body of research on this conceptualization of collaborative group engagement, the literature highlights the need to investigate it in more detail, using multi-method approaches and approaches that include different modes, such as nonverbal behaviors in addition to verbal group communication (Sinha et al., 2015; Rogat et al., 2022; Paneth et al., 2023).

## Nonverbal Indicators for QCGE

Previous research in CSCL has long included not only verbal but also nonverbal activities in its analysis of group processes, as for example recorded in activity transcripts (e.g., Rogat et al., 2022; Zahn et al., 2010). Seminal approaches to integrating nonverbal behaviors (e.g., eye contact, head nodding, gesturing) during social interaction into CSCL research range from the ethnographic research tradition (cf., Goldman et al., 2014) to more recent multimodal learning analytics and multi-method approaches (cf. Schneider et al., 2021; Paneth et al., 2023). Such research examines the nonverbal codes of kinesics, that is, all forms of body movements involving the head, gestures, facial expressions, and posture (for a broad overview of nonverbal codes, see Burgoon & Dunbar, 2018). A distinction can be made between nonverbal and coverbal behavior here: While nonverbal behavior includes all parts of communication except spoken language itself (Burgoon & Dunbar, 2018), coverbal behavior is characterized by gestures that coincide with speech, such as deictic pointing or iconic arm movements. As such, coverbal behavior conveys meaning beyond what language can express and is also inextricably linked to cognition and behavior as it reflects the speaker's thought processes (Kong et al., 2017). Furthermore, by representing the directional and dynamic aspects of linguistic content, coverbal gestures can enhance the semantic content of oral output (Kendon, 2000). In this paper, we address both nonverbal and coverbal behaviors and refer to them as nonverbal behaviors in the following to include both aspects.

Nonverbal aspects are important to consider when researching collaborative group processes such as QCGE, as the following reasons suggest: (1) *Theoretical Significance*: The role of nonverbal behaviors in QCGE is specified by recent theories of social interaction, which stress that nonverbal behavior in communication situations should not be seen as simple individual performances of group members, but rather as a dynamic system of nonverbal interactions within a given social environment (setting, group members)—with continuous parallel processes of social evaluations and social behavior of members mediated by cognitive–affective variables such as goals, affect, and interpersonal expectations (Patterson, 2019). Thus, successful social interaction requires that all members monitor the body language of others, interpret it in the context of the given social context or setting, and express their own behavior in accordance with it. In addition, the well-established Social Presence Theory (Short et al., 1976) suggests that, in communication situations, group members have a basic need to experience social presence, to feel validated and confirmed by other group members, through both verbal and nonverbal means (e.g., nodding of the head as an indicator of mutual reinforcement, e.g., Wittenbaum et al., 1999). (2) *Extensive Research base:* There is an extensive body of research on nonverbal behaviors and their relation to various aspects of human interactions, social relationships, and emotional expression: The broad literature on nonverbal expressions of dominance and power in interpersonal relationships suggests that the presence of certain body language can indicate the quality of social relationships

during intergroup interaction (e.g., Dunbar & Burgoon, 2005). Moreover, Husebø et al. (2011) found that deictic actions (pointing and positioning) were essential to achieving mutual understanding in student resuscitation teams, and Pi et al. (2019) showed that pointing and depictive gestures have a positive impact on students' learning performance in online lectures. Additionally, studies show that, in communication situations, leaning the upper body forward, nodding the head, and making eye contact indicate engagement and interest, supporting the chin on the hand indicates boredom and laughing, and smiling indicates enjoyment (Behoora & Tucker, 2015). Humor, expressed through laughing or smiling, is also part of positive socio-emotional processes in learning situations (Hu et al., 2021) and plays an important role in relationship development and in helping to lighten a serious learning topic (Hovelynck & Peeters, 2003). Additionally, open and moving arms and relaxed and extended eye contact have been found to be expressions of the basic emotion of happiness in individuals (Noroozi et al., 2018).

Recent approaches to *motion sensing* have linked body movements such as gestures and gaze to learning and group processes (for a review, see Schneider et al., 2021). Motion sensing refers to the use of technologies to capture and analyze individual or group body movements, gestures, and postures in educational and collaborative settings. It involves the measurement and analysis of physical movements, including body synchrony, specific types of gestures, and body postures, to understand learning processes, interaction patterns, and collaborative behaviors (Schneider et al., 2021). For example, Schneider and Blikstein (2015) used machine learning algorithms to analyze the body postures of learning dyads and found that prototypical body postures are related with learning gains. They discovered an "active" posture that is positively related with learning gains, and a "passive" posture that is negatively related with learning gains. Grafsgaard et al. (2014) found relationships between facial and gestural characteristics and student engagement and frustration. Spikol et al. (2017) used computer vision systems to detect wrist movements and facial orientation in small study groups and found that the distance between study group members' hands and the frequency of their glances at the shared screen could detect physical engagement. In previous exploratory work (Paneth et al., 2023), we correlated nonverbal behaviors with the four dimensions of QCGE and found, within a small sample of study group observations, that certain nonverbal behaviors, such as laughing, eye contact, and head nodding, were positively related to QCGE and thus represent a promising method for the detailed study of multifaceted engagement in CSCL.

The crucial role of nonverbal behavior in aspects of communication and learning applies not only to human-to-human communication situations but also to human-technology interactions. For example, Allmendinger et al. (2003) found that affirmative nonverbal behaviors of avatars, such as head nodding, increased learning motivation and a smooth communication process compared with a control group. In the realm of online collaboration, Schneider and Pea (2014) used eye-tracking technology to investigate collaborative problem-solving. They discovered that dyads achieved higher-quality collaboration and improved learning outcomes through mediated joint visual attention, such as mutual gaze and eye contact. Other research on joint visual attention has revealed its significant connection to learning groups' ability to maintain mutual understanding and learning gains (Schneider et al., 2018). Moreover, cooperating with artifacts in a shared workspace is indicative of learners' interest and participation in a task (Negrón & de Antonio Jiménez, 2009), and interacting with functional tools is indicative of a high quality of collaboration (cf. Rack et al., 2018).

In summary, collaborative group engagement in CSCL is increasingly being studied, but there is a need for research to shed more light on this complex construct using multi-method approaches, and the study of QCGE using nonverbal behaviors is a promising approach in this context. This brings us to the research questions we will pursue in the present study.

### The present study

The purpose of this study is to provide a deeper understanding of the specific role that nonverbal behaviors play in the dimensions of collaborative group engagement, as described in the "Introduction" section. Therefore, the present study aims to answer the following research questions:

1. Which nonverbal behaviors are indicative of which dimensions of the quality of collaborative group engagement in an authentic computer-supported collaborative learning design task?
2. What role do nonverbal behaviors play in sequences of high-quality collaborative group engagement versus sequences of low-quality collaborative group engagement within the four dimensions of behavioral, social, cognitive, and conceptual-to-consequential engagement?

To address these research questions, we combined quantitative and qualitative methods in our study as described in detail in the following section.

## Methods

### Study design

We conducted a laboratory study for the purpose of this research. We chose a controlled setting as our research design to effectively control our research variables (QCGE dimensions and nonverbal behaviors, as described in the "Measures" section) for thorough analysis and to ensure methodological and scientific rigor (Hmelo-Silver & Jeong, 2021). The study included low-structured and high-structured task conditions (see "Procedure" section). As the research addressed in the present paper is part of a broader study and our specific focus in this paper is on the relationships between nonverbal behaviors and QCGE dimensions, the two experimental conditions were not compared directly, but controlled for the factor of experimental condition in inferential statistical procedures (see "Analysis" section).

## Sample

Participants registered for participation in the study through a study enrollment system at the university in Switzerland, where the study was conducted. They were purposely selected via the call for the study to be unfamiliar with the Sweet Home 3D tool used in the study (see "Used Technology" section). In sum, 114 undergraduate psychology students divided into 38 groups of 3 participated (i.e., 14 groups (N = 42) within the high-structured task condition and 24 groups (N= 72) within the low-structured task condition). Their mean age was 22.4 years (SD 4.76 years), and 78% were female.

## Task

In this study, we employed a specific design task paradigm (Zahn, 2017). Architectural psychology served as an example domain in accordance with the context of the SNSF project in which the study is integrated (see "Acknowledgments"). More specifically, the students were asked to

work in groups of three using the three-dimensional (3D) modeling tool Sweet Home 3D (eTeks, 2022; see "Technology and materials" section) to collaboratively design a floorplan of a co-working office according to future users' needs. Each group member was randomly assigned the role of either a career consultant, a software developer, or a photographer, and each of these roles had specific requirements. The groups also had shared objectives, such as equitable space allocation, naming the office creatively, and sharing a kitchen. Moreover, the task included conflicting goals such as different setup requirements. The task's learning objectives included building domain-specific knowledge (connected to the subject matter of architectural psychology) and group-based collaborative problem-solving while using a complex digital planning tool.

## Procedure

Following common ethical standards (approved ethics vote: see "Declarations"), a formal consent form to be signed was provided to participants along with all study and data protection information. The participants then had 15 min to practice using the Sweet Home 3D software. After this individual training phase, the student groups received instructions according to the experimental condition to which they were assigned: Within the low-structured task condition, participants received instructions and information on how to complete the task and were given 70 min to complete the task. Within the high-structured task condition, the task performance time was divided into a 15-min planning phase, a 45-min processing phase, and a 10-min evaluation phase. Groups in this condition were given additional instructions for each phase: (1) Planning phase: They were given a sheet of paper to jointly plan their task approach, clarify common goals, and assign task roles. (2) Processing phase: They worked on the task and designed the shared office, considering individual and common needs. (3) Evaluation phase: They evaluated their collaboration and group product using a provided document that addressed task completion, goal achievement, and creativity. Group processes were video recorded for documentation and analysis. After completing the task, participants were given a questionnaire that asked for demographic information such as age and gender.

## Technology and materials

Sweet Home 3D (eTeks, 2022) is a 3D architecture software that allows to draw an interior and arrange it with various pieces of furniture. The application is available for free as a download and as a browser version. Since we intended to use a digital design tool within the domain of architectural psychology for our design task paradigm, Sweet Home 3D was a suitable application for our purpose. For the present study, we adapted the user manual supplied with the software and provided it to the participants to guide them during their task. Figure 1 shows a screenshot of the user interface of the Sweet Home 3D tool with a sample task outcome from our study.

## Setting

The study was conducted in the laboratory facilities of a Swiss university. Two monitors and a laptop computer, along with a keyboard and mouse, were set up on a large table so that all three members of the subject groups had sufficient space and access. With the two monitors, we ensured that all participants had a good view of the Sweet Home 3D

tool. Three chairs were placed side by side in front of the table. A Panasonic HC-X909 camera with a tripod was permanently installed about 1.5 m behind this arrangement so that it could record the upper bodies of all three group members at an angle of about 30° from above. As we focused on upper body nonverbal behaviors (Table 2) and used an authentic CSCL task paradigm (Zahn, 2017), this setting proved useful for our purposes. A Røde NT-USB Mini microphone was placed on the table to ensure adequate sound quality for the QCGE ratings, which included the analysis of verbal communication.

## Measures

### QCGE rating scheme

To capture the four dimensions of QCGE, that is, BE, SE, CE, and CC, we adapted a rating scheme (Sinha et al., 2015), which we have used in previous work (Paneth et al., 2023). The rating scheme was designed to sequentially rate the four dimensions of QCGE on the basis of the video recordings of groups engaged in a CSCL environment. The rating scheme (Table 1) consists of criteria by which a rater can determine whether a group's expression of each QCGE dimension is low, moderate, or high, and was initially applied to each 5-min sequence of video data (Sinha et al., 2015). To investigate QCGE in more detail, we applied the rating scheme to 1-min segments of our video material, following relevant video analysis methods (Zahn et al., 2021). This resulted in a total of $N = 2617$ ratings of each 1-min sequence from the entire video recordings for all four QCGE dimensions with the expressions low, moderate,

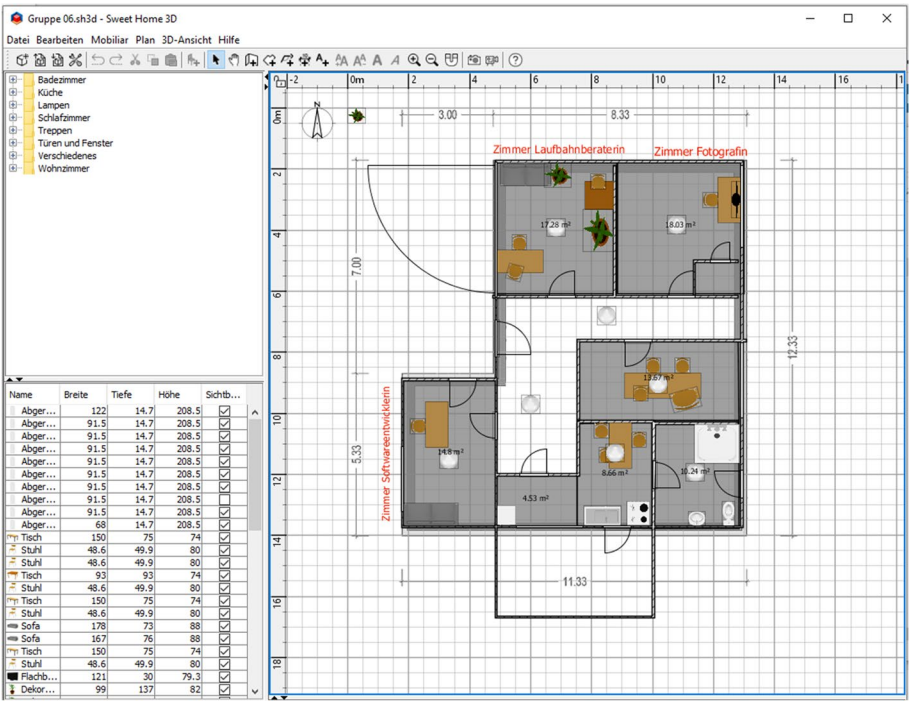


**Fig. 1** User interface of the Sweet Home 3D tool with sample task outcome

and high. To avoid bias in the data, sequences in which participants did not interact verbally or nonverbally were not rated and thus excluded from the analysis. Two trained raters tested the rating scheme by applying it to a subset of the 70 sequences of 1 min from a single group. To assess interrater reliability, we computed intraclass correlation coefficients (ICCs) for each rating dimension within the rating scheme, following the guidelines outlined in Koo & Li (2016). We used the R package "irr" (Gamer et al., 2019) to compute ICC estimates. This was done using a two-way mixed effects model with a mean rating ($k = 2$) and an absolute agreement criterion. Interrater reliability was calculated for each QCGE dimension. The results of the two raters showed moderate to good ICC values for the dimensions, with the following values: BE = 0.63, SE = 0.80, CE = 0.88, and CC = 0.67. Following this testing, two trained raters applied the rating scheme to all 1-min segments of the entire video material.

### Coding scheme for nonverbal behaviors

To assess participants' nonverbal behavior during the task, we adapted a coding scheme from previous work (Paneth et al., 2023), following established coding and counting methods for nonverbal behavior (Burgoon & Dunbar, 2018; Rack et al., 2018). A complete list of nonverbal behavior codes and their supporting literature is provided in Table 2.

The nonverbal indicators were coded using MAXQDA software (VERBI Software, 2021). Since our research interest was in the *frequencies* of nonverbal behaviors and their correlations with the QCGE dimensions, and we wanted to capture predetermined codes as features of communication (cf. Parks & Bennett, 2024), we deliberately used event-based coding and did so for each group member individually. This allowed us to capture frequencies of nonverbal behaviors of all group members during task performance even when occurring simultaneously. An example of the coding process in MAXQDA is shown in Figure 2. Four trained coders tested the coding scheme by applying it to a 10-min video sequence from a single group, and interrater reliability was determined again using ICC. The coders had excellent results: The ICC value was found to be 0.92. After the four trained coders applied the coding scheme to the entire dataset, we then aggregated the frequencies of the coded nonverbal behaviors for each code in each 1-min sequence.

Data collection for QCGE ratings and nonverbal behavior coding resulted in $N = 2617$ analyzed 1-min sequences.

### Learning outcomes

To measure learning outcomes, we created an expert rating grid for evaluating the collaborative group products (i.e., 3D models of the jointly designed co-working office; Fig. 1). It includes as domain-specific learning outcomes (see above on learning objectives) the achievement of common and individual goals as well as conflict resolution (i.e., whether the group found a solution to the conflicting goals) and creativity in design (i.e., whether, for example, the office community contains creative elements not specified in the task). The expert evaluation was based on a weighted scoring system, and the 3D models were scored from 1 (poor) to 6 (excellent) in tenths of a grade, consistent with the grading system used at Swiss universities. Two experts evaluated half of the group products (i.e., 19) in parallel. For interrater reliability, we calculated ICC again, resulting in a good ICC value of 0.825. After this test, one expert rated the other half of the group products. The expert rating grid is available in the Supplementary Material.

**Table 1** QCGE rating scheme for observed group behavior (adapted from Sinha et al., 2015)

| Dimension | Expression | Description |
|---|---|---|
| BE | Low | Only one group member is busy with the task or the whole group is off-task |
| | | Significant off-task conversations within the group |
| | | Limited task work or tool use |
| | Moderate | Two group members are engaged in the task while the remaining group members are not working on the task |
| | | Intermittent off-task behavior |
| | High | All group members are on-task |
| | | Group pursues task even in the face of distractions |
| | | Limited off-task discussion |
| SE | Low | Disrespectful or highly critical exchanges between group members |
| | | Ignoring or failing to integrate the contributions of one or more group members |
| | | Low group cohesion—indicated by an individual rather than a group task, e.g., individual processing of the task, use of "I" or a dominant group member doing all the work |
| | Moderate | One or two group members dominate by imposing their ideas, not resolving tensions or competing ideas but merely manipulating tools; contributions from group members are acknowledged and desired but not necessarily discussed or fully incorporated |
| | | Light to moderately disrespectful interactions |
| | | Group cohesion is mixed |
| | High | Contributions of all group members are acknowledged and included; respect for others' perspectives |
| | | Disagreement encourages further discussion, taking everyone's ideas into account and trying to find a solution |
| | | Tools, materials, and tasks are used collaboratively |

**Table 1** (continued)

| Dimension | Expression | Description |
|---|---|---|
| CE | Low | Lack of a plan, minimal planning, or vague plan; limited task monitoring |
| | Moderate | Group discusses action plan together, which may be incomplete or superficial |
| | | However, the group does not monitor the implementation of its plans and/or does not enact the plan as intended |
| | | Task monitoring focuses on a mix of superficial aspects as well as task completion, progress, and understanding |
| | High | Group has a plan that is being revised |
| | | Task plan focuses on moving toward solving the larger problem |
| | | Task monitoring focuses on conceptual understanding and use of scientific practice (e.g., use of evidence) |
| CC | Low | Task solutions are still based on low-level declarative knowledge, on facts; few connections are suggested |
| | | Limited use of evidence and resources (e.g., user manual, prior knowledge) |
| | Moderate | Group discussions and task work aim to build content links, but more importantly individual connections |
| | | The use of resources and justification is inconsistent |
| | High | Task solutions make connections between the content and the larger question |
| | | Consistent use of evidence, resources (e.g., user manual, prior knowledge) |
| | | Connections to content or scientific practices from other units |

**Table 2** Codes used for nonverbal behavior and related literature.

| Coded nonverbal behavior | Significance according to related literature | Related literature |
|---|---|---|
| Head nodding | Mutual reinforcement; engagement and Interest; nodding by avatars increases learning motivation and a smooth communication process | Allmendinger et al. (2003); Behoora & Tucker (2015); Wittenbaum, 1999 |
| Eye contact | Engagement and interest; relaxed and extended eye contact: basic emotion of happiness; higher-quality collaboration and increased learning through joint visual attention | Behoora & Tucker (2015); Noroozi, et al. (2018); Schneider & Pea (2014) |
| Supporting chin or cheek on hand | Boredom; frustration | Behoora & Tucker (2015); Grafsgaard et al., (2014) |
| Gesturing or pointing | Open and moving arms: basic emotion of happiness; deictic movements (pointing): beneficial for achieving mutual understanding and for learning performance | Husebø, et al., (2011); Pi et al., 2019 ; Noroozi, et al. (2018) |
| Leaning upper body forward | Engagement and interest | Behoora & Tucker (2015) |
| Computer operation | Interest and participation in a task; high quality of collaboration | Negrón, & de Antonio Jiménez (2009); Rack et al. (2018) |
| Laughing or smiling | Enjoyment; humor: positive socio-emotional process; helps lightening up serious learning topics | Behoora & Tucker (2015); Hovelynck & Peeters, 2003; Hu et al., 2021) |

## Analysis

To explore whether nonverbal behaviors reflected QCGE dimensions, we aligned the data points by aggregating occurrences of nonverbal codes per participant into frequencies within each 1-min sequence for each group (except for eye contact, which was coded at the group level, where we aggregated for each 1-min sequence and each group rather than at the participant level). Given the design of the observational data with repeated measures of nonverbal behavior frequencies and QCGE ratings and the hierarchical data structure where participants were grouped, we employed mixed effects models. We focused on the ratings of each QCGE dimension per minute and per group. As the QCGE ratings were ordinal, we used cumulative mixed models with the ordinal package in R (Christensen, 2019). This led to the formulation of seven models (i.e., one model for each nonverbal behavior code) for each QCGE dimension. To control for multiple testing, we applied the Bonferroni–Holm method and adjusted the alpha level accordingly (Holm, 1979). In each model, QCGE dimension ratings served as dependent variables and nonverbal behavior frequencies were included as fixed effects. Additionally, the study condition factor was incorporated as a fixed effect. To account for random effects at both the individual and group levels, we employed random intercepts, with participants nested within each group. Finally, to address convergence issues, we followed the approach recommended by Bates et al. (2015a). Methods for the qualitative case analysis are presented right before the qualitative results sections.

To test the relationship between QCGE and the learning outcome (i.e., grade), we calculated a linear regression model. To this end, we calculated average scores for each QCGE dimension, resulting in a continuous value for each group. The grade, which was on a continuous scale, functioned as the outcome variable, while the four QCGE dimensions were the predictors. In addition, to examine discriminative validity, we computed correlations between the QCGE dimensions as well as for the nonverbal behaviors. For this purpose, we used


**Fig. 2** Screenshot from coding process of nonverbal behavior coding scheme using MAXQDA software

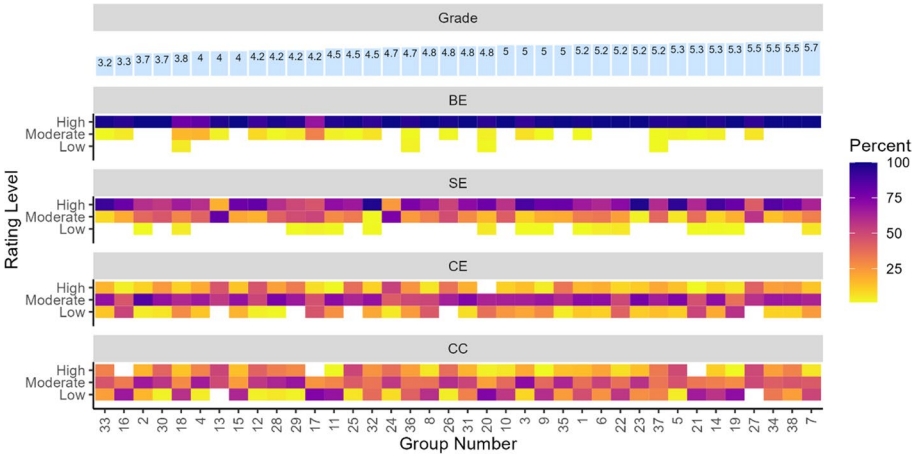


**Fig. 3** Proportions of QCGE ratings (i.e., low, moderate, and high) by dimension and group with each groups grade of the task product

Spearman's correlation coefficients $\rho$ for the QCGE dimensions, on the basis of the ordinal nature of the ratings. Similarly, based on the continuous nature of the frequencies, the correlation coefficients between the nonverbal predictors we used represent Pearson's $r$. Moreover, to examine, whether nonverbal behaviors were affected by the experimental conditions, we calculated an additional model. Given the design of the observational data with repeated measures of nonverbal behavior frequencies and the hierarchical data structure in which participants were grouped, we used mixed effects models. We defined condition as the outcome variable, nonverbal behaviors as fixed effects, and groups as random intercepts, resulting in one model. We used generalized mixed models with the "lmer" package in R (Bates et al., 2015b).

## Results

### Descriptive results

Figure 3 shows the relative frequencies and distributions of the QCGE ratings and the grades of each group. The results show that, for BE, for example, more than 90% of the ratings are on the high level, as indicated by the dark-colored top row. For SE, as indicated by the darker top row compared with the middle and bottom rows, the majority of ratings are also high. In contrast to BE and SE, the CE and CC ratings are more evenly distributed. Looking at selected groups, group 33, for example, has the lowest grade of 3.2 (i.e., the weakest group product). This group's BE and SE were most often high, which is indicated by the dark color in the top row. This group's CE and CC were most often moderate, again indicated by the darker color in this row. Group 7, on the other hand, with the best grade of 5.7, always had a high BE (i.e., only this row is filled in for this group), while CC was most often low.

Figure 4 provides an overview over the frequencies of nonverbal behaviors and depicts the mean frequencies for each nonverbal behavior per rating level (i.e., 1 = low, 2 =

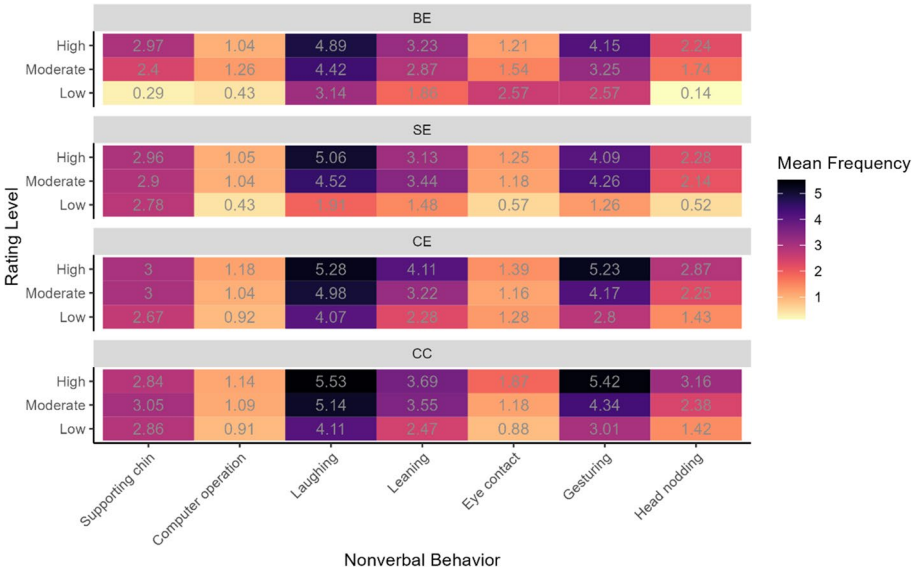


**Fig. 4** Mean frequencies per 1-min sequence of nonverbal behavior per rating level within the QCGE dimensions

moderate, and 3 = high) for the four QCGE dimensions (i.e., BE, SE, CE, and CC). Mean frequencies are aggregated across time and across groups. The results suggest that, for most nonverbal behaviors, there is a clear direction of relations to the four dimensions of QCGE; that is, frequencies of nonverbal behaviors increase with higher ratings. For example, the frequency of laughing increases strongly with higher ratings of SE: on average, laughing occurs 1.91 times when rated low and 5.06 times when rated high. As another example, the mean frequency of head nodding increases with higher ratings of CC: it is 1.42 times when rated low and 3.16 times when rated high. Note that the influence of group, condition, and order is not taken into account here, meaning that the descriptive statistics at some points appear different from the results of the inferential statistics (see next section).

## Nonverbal behaviors and their relation to QCGE dimensions

The following cumulative link mixed models were conducted with version 4.2.1 of R (R Core Team, 2023) in the R Studio environment (RStudio Team, 2020) and using the "ordinal" package (Christensen, 2019). In all models, the experimental condition (low versus high structure) was included as a fixed effect to control for possible effects. However, in none of the models did this fixed effect term show a significant effect on the outcome variables, meaning that the experimental condition did not influence the relationship between QCGE dimensions and nonverbal behaviors. The fixed effect for the control variable (i.e., experimental condition) is included in Tables 3, 4, 5 and 6 for comprehensive reporting along with the different predictors of nonverbal behaviors and the corresponding coefficient estimates, confidence intervals, and *p*-values. In the following, we report the results of the cumulative mixed models in the order BE, SE, CE, CC, with significant results highlighted in bold.

### Behavioral engagement

Table 3 presents the results of the cumulative link mixed models for BE. The results indicate that laughing or smiling are significantly and negatively related to BE. The odds ratios (OR) indicate rather small effect sizes: The odds ratio (OR) value of 0.86 implies a 14% increase in the odds of being rated lower on BE for each increase in laughing events (counts per minute). In other words: In sequences where the groups laughed a lot, their BE was of lower quality.

### Social engagement

Results of the cumulative link mixed models for SE are presented in Table 4. The results indicate that the nonverbal behaviors of head nodding, eye contact, gesturing or pointing, and laughing or smiling are significantly and positively related to SE. The ORs indicate rather small effect sizes: For example, the OR of 1.05 for gesturing or pointing implies a 5% increase in the odds of being rated at a higher level of SE for each one-unit increase in gesturing or pointing events (counts per minute). The OR of 1.16 for laughing or smiling, which implies a 16% increase in the odds of being rated at a higher level of SE, is the largest effect within the SE dimension. To summarize, in sequences where there was more nodding, laughing, gesturing, and eye contact, the groups had higher SE quality.

### Cognitive engagement

Table 5 presents the results of the cumulative link mixed models for CE. The results indicate that the nonverbal behaviors of nodding the head, supporting the chin or cheek on the hand, gesturing or pointing, leaning the upper body forward, and laughing or smiling are significantly related to CE. The ORs again show rather small effect

**Table 3** Results of the cumulative-link mixed models: BE

| | **BE** | | |
|---|---|---|---|
| *Predictor* | *OR* | *CI* | *p* |
| Head nodding | 1.12 | 0.98–1.28 | 0.101 |
| Eye contact | 1.00 | 0.91–1.09 | 0.931 |
| Supporting chin or cheek on hand | 1.16 | 1.03–1.31 | 0.015 |
| Gesturing or pointing | 1.11 | 1.01–1.21 | 0.023 |
| Leaning upper body forward | 0.99 | 0.87–1.13 | 0.864 |
| Computer operation | 1.06 | 0.89–1.26 | 0.521 |
| **Laughing or smiling** | **0.86** | **0.77–0.95** | **0.004*** |
| Control: Condition | 0.65 | 0.21–2.04 | 0.458 |

OR, odds ratio; CI, 95 % confidence interval

* $p <$ adjusted α

**Table 4** Results of the cumulative-link mixed models: SE

| | SE | | |
|---|---|---|---|
| *Predictor* | *OR* | *CI* | *p* |
| **Head nodding** | **1.14** | **1.09–1.20** | **<0.001*** |
| **Eye contact** | **1.09** | **1.05–1.14** | **<0.001*** |
| Supporting chin or cheek on hand | 1.04 | 0.99–1.08 | 0.097 |
| **Gesturing or pointing** | **1.05** | **1.02–1.09** | **0.002*** |
| Leaning upper body forward | 1.01 | 0.97–1.06 | 0.563 |
| Computer operation | 1.06 | 0.98–1.14 | 0.166 |
| **Laughing or smiling** | **1.16** | **1.11–1.22** | **<0.001*** |
| Control: Condition | 1.22 | 0.64–2.31 | 0.543 |

OR, odds ratio; CI, 95% confidence interval

* $p <$ adjusted $\alpha$

**Table 5** Results of the cumulative-link mixed models: CE

| | CE | | |
|---|---|---|---|
| *Predictor* | *OR* | *CI* | *p* |
| **Head nodding** | **1.10** | **1.06–1.15** | **<0.001*** |
| Eye contact | 0.99 | 0.95–1.03 | 0.530 |
| **Supporting chin or cheek on hand** | **1.07** | **1.03–1.11** | **0.001*** |
| **Gesturing or pointing** | **1.11** | **1.08–1.14** | **<0.001*** |
| **Leaning upper body forward** | **1.12** | **1.07–1.17** | **<0.001*** |
| Computer operation | 1.06 | 0.99–1.13 | 0.080 |
| **Laughing or smiling** | **0.95** | **0.92–0.99** | **0.009*** |
| Control: Condition | 1.16 | 0.58–2.32 | 0.676 |

OR, odds ratio; CI, 95% confidence interval

* $p <$ adjusted $\alpha$

**Table 6** Results of the cumulative-link mixed models: CC

| | CC | | |
|---|---|---|---|
| *Predictor* | *OR* | *CI* | *p* |
| **Head nodding** | **1.16** | **1.12–1.21** | **<0.001*** |
| **Eye contact** | **1.17** | **1.12–1.22** | **<0.001*** |
| **Supporting chin or cheek on hand** | **1.06** | **1.02–1.10** | **0.003*** |
| **Gesturing or pointing** | **1.15** | **1.12–1.19** | **<0.001*** |
| **Leaning upper body forward** | **1.05** | **1.01–1.09** | **0.018*** |
| Computer operation | 1.05 | 0.98–1.12 | 0.154 |
| Laughing or smiling | 0.98 | 0.95–1.02 | 0.368 |
| Control: Condition | 1.19 | 0.49–2.43 | 0.832 |

OR, odds ratio; CI, 95% confidence interval

* $p <$ adjusted $\alpha$

sizes. While the first four indicate a positive relationship, laughing is negatively related to CE, with the OR of 0.95 indicating a 5% increase in the odds of being rated lower on CE for each increase in laughing events (counts per minute). Leaning forward had the largest effect on this QCGE dimension, with an OR of 1.12, implying a 12% increase in the odds of being rated higher on CE for each one-unit increase in this nonverbal behavior. In short, in sequences where there was more laughing or smiling, the groups showed lower-quality CE, and in sequences where there was more nodding, supporting the chin on the hand, gesturing, and leaning forward, the groups showed higher-quality CE.

### Conceptual-to-consequential engagement

Table 6 presents the results of cumulative mixed models for CC. The results suggest that the nonverbal behaviors of head nodding, eye contact, chin or cheek support on hand, gesturing or pointing, and upper body lean forward are significantly and positively related to CC. Within this dimension, the ORs also indicate rather small effect sizes. Eye contact had the largest effect on CC, implying a 17% increase in the odds of being rated as having a higher level of CC for each unit increase (counts per minute). The nonverbal behavior of leaning forward had a very small effect (OR = 1.05). In other words, in sequences where head nodding, eye contact, supporting the chin on the hand, gesturing, and leaning forward occurred more frequently, the groups showed a higher quality of CC.

## QCGE dimensions and learning outcomes

The results of the linear regression model show that the effects of BE ($\beta = 3.01$), SE ($\beta = 0.31$), CE ($\beta = 0.42$), and CC ($\beta = –0.52$) on the learning outcome (i.e., grade) are statistically nonsignificant, with $p$-values above the conventional significance threshold ($p < 0.05$). Thus, none of the QCGE dimensions demonstrated a statistically significant impact on the learning outcome, with confidence intervals for all betas spanning values that include zero, indicating uncertainty around their true effect sizes. The results table is available in the Supplementary Material.

## Correlations

Figure 5 shows the correlation coefficients between the QCGE dimensions and between the nonverbal behaviors. As noted in the "Analysis" section, the correlation coefficients for the QCGE dimensions represent Spearman's $\rho$ and the correlation coefficients for the nonverbal behaviors represent Pearson's r. The Spearman's $\rho$ results suggest that the QCGE dimensions are weakly correlated with each other, except for CE and CC, indicating a moderate effect size. In addition, the nonverbal behaviors partially show weak to moderate effect sizes according to the Pearson's $r$ correlation coefficients. Regarding the possibility of multicollinearity for the prediction of QCGE

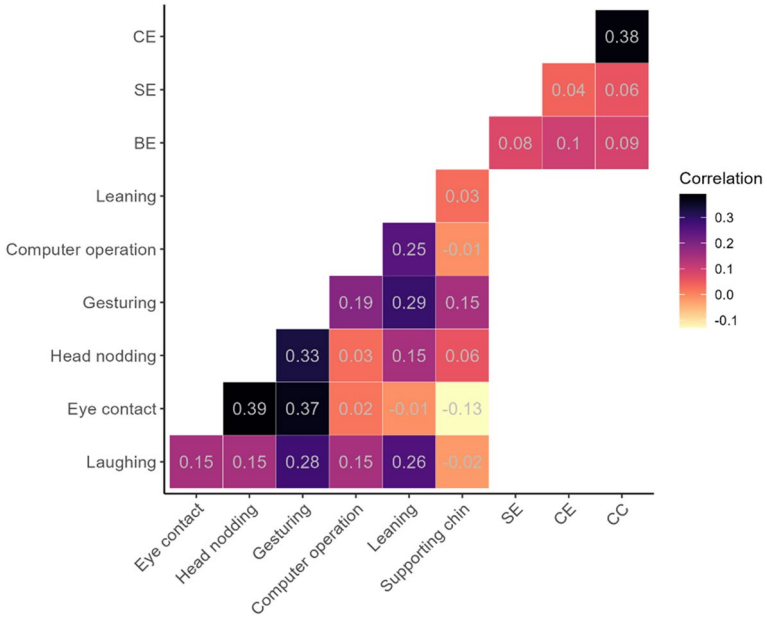


**Fig. 5** Correlation plot of QCGE dimensions and nonverbal predictors

based on the nonverbal predictors, the correlation coefficients do not suggest multicollinearity (Shrestha, 2020).

As indicated in the "Analysis" section, we calculated an additional model to examine whether nonverbal behaviors were affected by the experimental conditions. The results show no significant relationship between the nonverbal behaviors and the experimental condition. The results table is available in the Supplementary Material.

The above-described quantitative analysis clearly shows correlations between certain nonverbal behaviors and various dimensions of QCGE. These results are already very promising and show that various nonverbal behaviors, as also suggested in relevant literature (see Table 2), do indeed play an important role in sensing the quality of collaborative group engagement. However, despite the importance of these findings, the question of *how exactly* the related nonverbal behaviors play a role in the QCGE dimensions leads us to the need for further qualitative analysis. While quantitative research can reveal relationships between different variables, qualitative analysis allows us to delve deeper into the underlying group processes related to QCGE and focus on the precise interactions and conditions that lead to these findings (Hmelo-Silver & Jeong, 2021). With the qualitative in-depth analysis described in the following sections, we address the second research question, namely "What role do nonverbal behaviors play in sequences of high-quality collaborative group engagement versus sequences of low-quality collaborative group engagement within the four dimensions of behavioral, social, cognitive, and conceptual-to-consequential engagement?"

## Zooming in: Qualitative case analysis

### Method

We conducted a qualitative analysis based on group interaction analysis (Brauner et al., 2018; Jordan & Henderson, 1995), case analysis (Koschmann & Schwarz, 2021), and video analysis methods for small groups (Zahn et al., 2021) to explore in depth the correlations between nonverbal behaviors and QCGE dimensions (see Tables 3, 4, 5 and 6). Specifically, we examined the characteristics of high- and low-quality QCGE sequences in terms of nonverbal behaviors within the observed groups and the functions these nonverbal behaviors serve in relation to the different QCGE dimensions. To this end, we first thoroughly explored the data to select appropriate cases (Koschmann & Schwarz, 2021): We first selected sequences (i.e., 1-min video segments of the studied groups) that contrasted in quality along the QCGE dimensions, i.e., sequences with low and high QCGE quality. Within this sample, we further selected sequences in which nonverbal behaviors were significantly related to the QCGE dimensions (see Tables 3, 4, 5 and 6), and we focused on sequences in which there was a lot of the related nonverbal behavior when the relationship was positive and vice versa. Specifically, fewer than two and more than ten nonverbal behaviors per minute proved useful as frequency thresholds (i.e., frequency of 0–2 for "little" and 10 or more for ""much/a lot of" nonverbal behavior). For example, for SE, head nodding is positively related, and we selected high-quality SE sequences with more than ten head nods versus low-quality sequences with fewer than two head nods as cases for qualitative in-depth analysis. As a further narrowing criterion for case selection, we decided to focus on relationships with odds ratios above 1.10 and below 0.90, which allowed us to focus on the strongest relationships between QCGE dimensions and nonverbal behaviors. The selected sequences were then carefully reviewed, and notes taken for detailed description, analysis, and interpretation. Particularly illustrative sequences were then prepared as exemplary case illustrations. Note that, in this qualitative analysis, we deliberately separated the research steps of coding and counting (see "Coding scheme for nonverbal behaviors" section) and transcribing nonverbal behaviors. The transcriptions (i.e., case analysis of selected sequences) were done specifically for the purpose of case illustration. Therefore, the transcriptions of the cases are condensed for illustrative purposes. In the following sections, we present findings from our qualitative case analysis.

### Having fun despite distractions: The relation between behavioral engagement and laughing or smiling

Sequences with high-quality BE are characterized by groups in which all group members are active and seemingly interested on-task, that is, they are actively focusing on the screen, and they are discussing the task to be worked on together, either content-wise or about how to go on within the collaborative process. The groups in these sequences appear serious and focused; accordingly, there is not much laughing.

Low-quality BE sequences are characterized by the fact that the groups are either off-task and talk about private topics, or they are off-task most of the time and are making a lot of jokes and not taking the task very seriously at that moment. In these sequences, however, the groups seem to be having a good time and enjoying themselves, which is underlined by frequent laughing or smiling at each other. Thus, in these sequences, the

low-quality BE does not seem to have a negative, but sometimes even rather a positive, influence on the group work, because the atmosphere in these sequences seems relaxed and familiar.

In this sequence from group 36, the group members have just read through the task; the task processing time is still at the beginning. P1 is still reading; the other two and then later also P1 talk about their sleeping habits. More specifically, they talk about how they all had trouble getting up that morning and talk about their "snoozing habits," as depicted in Table 7.

The atmosphere in this sequence seems to be very relaxed and familiar; accordingly, the group members keep smiling at each other and sometimes laugh together, e.g., at min. 00:05:53 when P2 tells that she once snoozed for 3 h during a stay in the mountains, whereupon the other two and she herself burst out laughing. This relaxed atmosphere seems to be supported by the frequent smiling and laughing.

### "We Can Certainly Find a Solution": The relation between social engagement and laughing or smiling and head nodding

Sequences of high-quality SE are characterized by a lot of social interaction, both verbal and nonverbal, that is constructive, friendly, respectful, and inclusive. In these sequences, the groups seem to get along well and have found common ground. All three group members actively and equally participate in the conversation, and each contribution is noticed and responded to, always in a friendly manner. Furthermore, groups in these sequences sometimes joke, but still remain focused and on-task. Accordingly, there is a lot of laughing or smiling and head nodding in these sequences, which seems to contribute to a relaxed and trusting atmosphere by having a loosening, affirming, and reinforcing effect.

As shown in Table 8, the three group members collect one by one the individual requirements they need to fulfill for their shared co-working office in this sequence of group 28.

In this sequence, while one group member is talking, the other two are each listening actively, which is also expressed verbally (i.e., "yes," "mhm," etc.) as well as nonverbally with frequent head nodding. Moreover, the three laugh together when a content seems funny to them, e.g., starting at minute 00:21:08, where P2 tells that her role (the software developer) wants a better name for the co-working office than "Four Hair Seasons" (a German pun that does not translate well), she herself laughs about it and the other two join in the laughing. In addition, the three group members often smile at each other when one of them is talking. This laughing and smiling underscores the positive group atmosphere and thus the high-quality SE that prevails in this sequence. The relation between the laughing, smiling, and head nodding with high-quality SE is visible here in the sense that the nonverbal behaviors seem to support group cohesion, respectful and responsive interaction, and a positive group climate. Interestingly, each group member has approximately equal time to narrate their role-specific requirements for the group task (give or take 1 min), which again underscores the high-quality SE, demonstrating that all group members are equal, and all contributions are included to the same extent in the group discussion.

The characterization of sequences in which SE was low quality is that of low overall social interaction—correspondingly, the two nonverbal behaviors related with SE, laughing or smiling, and head nodding, are rare. These sequences can be roughly divided into two interaction patterns: (1) All three or two group members are on task, but there is little

**Table 7** Case illustration of selected example sequence with low-quality BE and laughing or smiling

| Time | | Verbal communication | Laughing or smiling |
|---|---|---|---|
| 00:05:07 | P2: | I had super trouble getting up this morning. I have not been up so early for a super long time. | P2<br>P2 |
| 00:05:12 | P3: | Mhm. | |
| 00:05:14 | P3: | I set three alarm clocks for myself. | |
| 00:05:17 | P2: | I always set myself three alarm clocks. | P2 |
| 00:05:20 | P3: | Ah no, I'm actually always awake after the first alarm. | P2, P3 |
| 00:05:27 | P2: | Ah, me never. | P2 |
| 00:05:28 | P3: | But today it didn't work at all. | P3 |
| 00:05:31 | P2: | I usually still reset my third alarm clock. | P2, P3 |
| 00:05:34 | P3: | Snooze button. | |
| 00:05:36 | P2: | No. No, without snooze. I really switch it manually and still fall asleep again. | P2<br>P2, P3 |
| 00:05:41 | P3: | I can't. When I'm awake, I'm awake. | |
| 00:05:43 | P2: | That's cool, though. | |
| 00:05:44 | P3: | Then I can't fall asleep again. | |
| 00:05:45 | P1: | Whoa. I always snooze a hundred times. | P1, P2, P3 |
| 00:05:49 | P2: | Yeah. | P2 |
| 00:05:50 | P3: | It makes me so nervous because I know I have to get up. | P1, P3 |
| 00:05:52 | P1: | Yeah. | |
| 00:05:53 | P2: | I once snoozed in the mountains for three hours | P2 |
| 00:05:57 | P3: | What? | P1, P2, P3 |
| 00:05:58 | P2: | And every ten minutes the stupid alarm clock went off. | |

verbal or nonverbal interaction, and if there is some verbal or nonverbal expression, it is not always actively responded to. In other words, the group is unresponsive and therefore not actively collaborating at that moment but is individually focused. (2) Rarely observed: Power relations seem to be unequal, meaning that one or two group members dominate the collaboration, while one group member holds back and seems shy. In these sequences, the response to a question may be harsh or angry, the question may be ignored altogether, or one group member may mock the statements of another.

In this low-quality SE sequence of group 11, shown in Table 9, the group is in the second half of the task processing time and again collects the requirements that each role of the group members must fulfill.

P1 says what his role needs for the common co-working office, while P2 seems to find it inappropriate that P1 needs so much space and makes fun of him (from minute 00:48:24). P1 tries to justify himself, but P2 interrupts him and asks if he can have some of P1's space, laughing. P3 remains verbally and nonverbally inactive in this sequence and seems bored or annoyed. Moreover, P2 keeps cutting the word of P1, who in turn remains silent for a moment. Laughing only occurs with P2 when making fun of P1, and is not reciprocated by the other two group members. There is also no head nodding in this sequence, which seems to reflect the rather tense atmosphere of this low-quality SE sequence; therefore, there is—nonverbally and verbally—not an atmosphere of approval and trust.

**Table 8** Case illustration of selected example sequence with high-quality SE, head nodding, and laughing or smiling

| Time | | Verbal communication | Head nodding | Laughing or smiling |
|---|---|---|---|---|
| 00:21:00 | P2: | Exactly. And it would be super important to me if we could find a cool name together that's creative, not like, yes, there's a hairdresser next door, but it's called Four Seasons of Hair, which I think is stupid. | | P1 |
| | | | P3 | |
| | | | P1 | |
| | | | | P1, P3 |
| | | | P2 | P1, P2, P3 |
| 00:21:20 | P2: | So I'd rather have something peppy. Yes, and what else is important to me? Yes, a terrace, I don't know if that is also in your interest, and, yes, a bathroom with shower, if possible, and a kitchen for lunch. | | |
| | | | P1, P3 | |
| | | | P3 | |
| | | | P1, P3 | |
| | | | P3 | |
| 00:21:45 | P2: | Yeah, exactly. | P1 | |
| | | | P3 | P1, P2, P3 |
| 00:21:49 | P1: | Um. Then I'll continue? | | |
| 00:21:50 | P2: | Mhm. | P3 | P2 |
| 00:21:51 | P1: | So, I would also like to have my own little workspace, um because I also have guests and then (inaudible) um, those and therefore generally a meeting room with a big meeting table, that would be good. | | |
| | | | | P1 |
| | | | | P1, P2 |
| 00:22:12 | P3: | Mhm. | P2, P3 | P3 |
| 00:22:14 | P1: | Um... And I would like to be close to the kitchen because I like to have snacks. | | P1 |
| 00:22:21 | P2: | Perfect. | | P1, P2, P3 |
| 00:22:25 | P1: | And also a common big terrace would be nice, also a bathroom and the possibility to shower, because I like to do yoga and go jogging. | | P2 |
| | | | P3 | P1 |
| 00:22:38 | P1: | Exactly. And that's actually all. Oh yes, not too much visual stimuli at work, because that bothers me, I don't tolerate that well. | | |
| | | | | P1, P2 |
| | | | P2, P3 | |
| 00:22:51 | P1: | Yes. That would be that. | P1 | P1 |
| 00:22:53 | P2: | Okay, mhm. | P2, P3 | |

**Table 8** (continued)

| Time | | Verbal communication | Head nodding | Laughing or smiling |
|---|---|---|---|---|
| 00:22:57 | P3: | So I also have the common needs that we all have. | P2 | |
| 00:22:59 | P1: | Yeah. | P1, P2 | P1 |
| 00:23:00 | P3: | And for me personally, I need a rather larger space for my photo studio. | P2 | |
| 00:23:04 | P1: | Mhm. | P1 | P1 |
| 00:23:06 | P3: | so that I can also give free rein to my creativity there. And in addition, I need a small work area for me, for my, for editing and um, also a small wardrobe for my customers that they can change. | P1 | P1 |
| | | | P1, P2 | |
| | | | P2 | |
| | | | P1 | P1, P2 |
| | | | P2 | |
| | | | P1 | |
| 00:23:24 | P2: | Yeah. | P2 | |
| 00:23:26 | P3: | And what's important for me is that it doesn't have too many office plants because I'm allergic to some. | P1 | |
| | | | P2 | |
| 00:23:36 | P3: | And, yes, on the walls, that should still have room for my pictures, that I can do a little, that I can do a little advertising, but that can also be in my office. | P1 | PI |
| | | | P1 | |
| 00:23:49 | P2: | Mhm. | | P2, P3 |
| 00:23:50 | P3: | So I can compromise on that. | P2 | |
| 00:23:52 | P1: | Okay. | P1 | |
| 00:23:56 | P2: | Okay well, so I think we can certainly find a solution there. | P1, P3 | P1, P2, P3 |

**Table 9** Case illustration of selected example sequence with low-quality SE, head nodding, and laughing or smiling

| Time | | Verbal communication | Laughing or smiling |
|---|---|---|---|
| 00:48:00 | P1: | I am simply a software developer, who needs all that - | |
| 00:48:06 | P2: | Good. He who needs everything. | |
| 00:48:19 | P1: | Yes, with me that's all then. | |
| 00:48:24 | P2: | That's it? You don't need that much space for that! | P2 |
| 00:48:27 | P1: | Bookshelf... yes, it doesn't actually say what - | |
| 00:48:32 | P2: | Can I have some of that office space you've got? | P2 |
| 00:48:40 | P1: | Yes, I, it just says that I like to drink coffee, need joint sessions with guests, but it does not say exactly what I do - | |
| 00:48:50 | P2: | But for the session you can also work in the meeting room. | |

## "Good to Keep Track of Time": The Relation between cognitive engagement, gesturing or pointing, and leaning the upper body forward

Sequences with high-quality CE are characterized by active and joint planning, coordination, and thus a socially shared regulation of the collaborative process. Accordingly, there is frequent gesturing or pointing, and leaning of the upper body forward. This nonverbal behavior seems to directly support joint task coordination, for example, when one group member leans forward to align with another group member while suggesting what task the other group member should take on and pointing to the shared screen to support shared understanding.

Group 26 has just read through all the instructions and quickly begins coordinating work in this sequence of group work, as shown in Table 10.

CE was high in this sequence, as evidenced by the group actively discussing a plan for how they want to proceed during task processing. Leaning the upper body forward and gesturing or pointing occurred frequently in this sequence. As a gesture, one group member often points to another to nonverbally emphasize task coordination, e.g., at minute 00:10.05, when P1 says that either she or P2 should operate the computer, pointing to herself and to P2 in turn. Leaning the upper body forward seems to serve different functions here: On the one hand, the group members often lean forward to align with each other, facing the other person to whom they are also verbally addressing. Another function seems to be to take a closer look at something: in this sequence, for instance, the group members lean forward to look at the SH3D tool on the screen more closely. Thirdly, leaning forward also seems to have a verbal reinforcing function: P1 leans forward at minute 00:10:30 and at the same time spreads both hands flat in front of her to underline the verbally said "Yes. But" to demonstrate that she is willing to take over the time management, but she is also open to take over another responsibility. These nonverbal behaviors seem to facilitate verbal communication, coordination, and planning of the common task and thus serve the development of mutual understanding.

Sequences in which CE was low quality can be characterized in two ways: First, there are sequences in which the groups are in a "focused execution" phase: For the most part, one group member operates the shared tool and the other two are focused, instructing, or helping with the implementation of their co-working office. In this phase, joint planning

**Table 10** Case illustration of selected example sequence with high-quality CE, gesturing or pointing, and leaning upper body forward

| Time | | Verbal communication | Gesturing or pointing | Leaning forward |
|---|---|---|---|---|
| 00:10:00 | P3: | How do we want to distribute the roles? Who wants to do what? I am quite indifferent. | | P1 |
| | | | | P1, P2 |
| 00:10:06 | P1: | I don't care either. I think that either you or I will operate this. | | |
| | | | | P2 |
| | | | P1 | P2, P3 |
| | | | | P3 |
| 00:10:12 | P3: | Okay, I would also say so. Who wants? | | |
| | | | P3 | |
| 00:10:14 | P2: | Then, let's do it so that you're operating this. I do that. | P2 | |
| 00:10:17 | P1: | Mhm. And you do that. | P1 | P2 |
| 00:10:19 | P3: | Mhm. | | P1, P2 |
| 00:10:20 | P1: | The time is still to be settled, the time. | | |
| | | | | P1, P2, P3 |
| | | | | P1, P3 |
| | | | | P1 |
| 00:10:24 | P1: | Well, I am Anna. | | |
| 00:10:25 | P2: | Nadine. | | |
| 00:10:26 | P1: | Good to keep track of time. | P3 | |
| 00:10:28 | P2: | You? | P2, P3 | P1 |
| 00:10:29 | P1: | Yes. But… | | |
| | | | P1 | P1 |
| 00:10:31 | P3: | So did you say you wanted to manage the time or not? | | |
| | | | P3 | |
| 00:10:37 | P1: | Well, I can do it, but I don't care.... | P1 | |
| 00:10:39 | P3: | Okay, are you managing the computer then? | P3 | |
| 00:10:41 | P2: | Ok. Yes. | | |
| 00:10:43 | P3: | Nadine, right? | | P2 |
| 00:10:44 | P2: | Yes. | | P1, P2 |
| 00:10:47 | P2: | Oh my. | | |
| 00:10:49 | P3: | And your name was? | | P2, P3 |
| | | | | P1, P2, P3 |
| 00:10:51 | P1: | Anna. | | P1, P3 |
| 00:10:52 | P3: | And I am Helga. | | |
| 00:10:58 | P1: | How do you write that? | | P1 |
| 00:10:59 | P3: | H, E, L, G, A. | | |

and coordination of the task does not seem to be a priority because the group is executing single steps of the task, albeit rather superficially. Accordingly, leaning the upper body forward or gesturing or pointing doesn't seem to be necessary in this phase of collaboration. Second, some sequences are also characterized by the fact that the group is

**Table 11** Case illustration of selected example sequence with low-quality CE

| Time | | Verbal communication |
|---|---|---|
| 00:52:00 | P1: | So, the time is already pretty tight. |
| 00:52:03 | P3: | A little bit, yeah. |
| 00:52:05 | P2: | (inaudible) |
| 00:52:07 | P3: | What are you trying? |
| 00:52:08 | P2: | (inaudible) straight. |
| 00:52:09 | P3: | Just in the middle of the room? |
| 00:52:11 | P2: | Yes, here. |
| 00:52:12 | P3: | Yes, in the middle of the room. |
| 00:52:14 | P2: | No, (inaudible) table, with chair. |
| 00:52:19 | P3: | Okay. |
| 00:52:20 | P2: | Huh, where did the table go? |
| 00:52:30 | P3: | What, uh, what kind of thing? |
| 00:52:33 | P2: | Never mind. Now we just have now.... never mind. |
| 00:52:43 | P2: | We all need a laptop. |
| 00:52:48 | P1: | A piano. What the fuck. |
| 00:52:51 | P2: | What kind of table? Uh chair. |
| 00:52:54 | P3: | Whatever you want. |

trying to perform the task, but they are not yet familiar with the tool. In these sequences, the group lacks a concrete plan of action or coordination; they are in the process of agreeing on how to use the tool. Often the group seems either overwhelmed or bored by the demands of the task and shows little interest or motivation, which is also evident by a more rigid body posture—there is no "interested leaning forward" and no "coordinating pointing or gesturing."

Group 15 is in the second half of the task completion period and is currently focused on executing individual steps to design their co-working office as displayed in Table 11.

CE was low quality in this sequence, which is evident in the fact that the group does not follow a concrete plan and seems to be either overwhelmed or indifferent, even bored with the task at hand, e.g., from minute 00:52:30, when P3 asks what kind of thing P2 means and P2 says "never mind…". Further, the task processing refers to superficial aspects that seem to result from the fact that the group members are not yet completely comfortable with the tool (e.g., at minute 00:52:20, P2: "huh, where did the table go?"). Accordingly, no nonverbal behavior related with CE (i.e., gesturing or pointing, leaning the upper body forward) is evident in this sequence; the three group members look relatively fixedly at the screen.

### Making connections: The relation between conceptual-to-consequential engagement, gesturing or pointing, eye contact, and head nodding

High-quality CC sequences are characterized by group members actively using resources (i.e., user manual, task description, and own prior knowledge) to solve the task, keeping the overall task and its solution in mind, and making connections between

**Table 12** Case illustration of selected example sequence with high-quality CC, gesticulation, eye contact, and head nodding

| Time | | Verbal communication | Gesturing or pointing | Eye contact | Head nodding |
|---|---|---|---|---|---|
| 00:26:00 | P1: | And then the kitchen. | | P2, P3 | P2 |
| 00:26:01 | P2: | Okay. | P2 | | |
| | | | P1, P2 | | P3 |
| 00:26:03 | P1: | You still need an office, don't you? | P1 | | |
| 00:26:05 | P3: | Yes. But I don't need so much stuff there. So just... | | P1, P2 | P3 |
| 00:26:09 | P1: | Ah, just a desk. | | P1, P2, P3 | P1 |
| 00:26:11 | P3: | Mhm. | | | P3 |
| | | | | P1, P3 | P1 |
| 00:26:13 | P1: | Ok. I need everything. | | | |
| | | | P3 | P1, P2, P3 | P3 |
| 00:26:15 | P2: | Hehe. Um... So you wanted your office here, right? | P2 | | |
| 00:26:22 | P1: | So just to get away from the kitchen so it doesn't smell like food. | | | |
| 00:26:26 | P2: | Okay. | | | P2 |
| | | | | | P1, P3 |
| 00:26:29 | P2: | Okay. You want to have plants, right? | | P1, P3 | |
| | | | P2 | P1, P2, P3 | |
| 00:26:31 | P1: | Mhm. | | P1, P2 | P1 |
| 00:26:32 | P2: | Okay. I don't. Then would it be okay if your workplace was somehow here? | | | |
| | | | | P2, P3 | |
| 00:26:37 | P3: | Yeah. | | | P3 |
| | | | P2 | | P2 |
| 00:26:40 | P3: | But we need another meeting room like that, don't we? | | P1, P2 | P1 |
| 00:26:43 | P1: | Yes, we can put it next to my office. | P1 | P1, P3 | |
| 00:26:45 | P2: | Yes, so in the middle here. | P1 | | |
| 00:26:46 | P3: | Mhm. | | P1, P3 | P2, P3 |
| 00:26:48 | P2: | Okay. Let's do the walls. | | | |

**Table 12** (continued)

| Time | | Verbal communication | Gesturing or pointing | Eye contact | Head nodding |
|---|---|---|---|---|---|
| 00:26:55 | P1: | So I just need couch, couch table and a desk. | P1 | P1, P2, P3 | |

their ideas—in this case, trying to combine different requirements into a co-working office that takes all requirements into account. This connection making also seems to be reflected in nonverbal behavior: There is a lot of eye contact, gesturing or pointing, and head nodding. These nonverbal behaviors seem to support the demands of this higher-level engagement dimension: Here, active collaboration and thoughtful linking of information and resources seem to be supported by group members making direct eye contact, acknowledging suggestions with head nods, and emphasizing communication with meaningful gestures.

Group 29 has just collected the individual requirements for each role and is now beginning to discuss how it might integrate these different requirements, as demonstrated in Table 12.

In this sequence of group 29, as displayed in Table 12, high-quality CC is evident in the group's use of existing resources (here: task description) and actively connecting individual information (which role needs which office equipment) while keeping in mind the overall goal of the task (i.e., integrating the different requirements), e.g., at min. 00:26:31, when P2 collects the individual info (i.e., P1 needs plants but P2 does not) and suggests solutions (placement of rooms to fit everyone). At the same time, the verbal interaction in the group is strongly complemented by frequent eye contact, head nodding, and gesturing. These three behaviors seem to serve a strong affirmative function in this sequence, which in turn supports the development of CC. The nonverbal behaviors here, especially eye contact, seem to help build a connection between group members, both mentally (i.e., finding common ground) and substantively (between individual ideas and requirements). Here, both the high-quality CC and the corresponding nonverbal behaviors together seemed to contribute to the conceptual understanding of the common task and the larger goal of the collaboration as the group members continued to discuss the common requirements.

Sequences in which CC is low quality are characteristically similar to low CE sequences. They are characterized by the group being in the process of performing its task; that is, one group member is operating the tool while the others are actively involved, instructing and/or helping the operating group member. Here, this form of QCGE and thus actively connecting ideas and using resources does not seem to be a priority because group members are in a focused execution phase. Similarly, the related nonverbal behavior does not seem necessary because the group is jointly focused on the tool and less on each other. But, as also in low-quality CE sequences, there are individual sequences in which the group seems overwhelmed, bored, or annoyed, and where there is also no room for confirmation and reinforcement with nonverbal behavior.

In this sequence of group 1, displayed in Table 13, group 1 is still at the beginning of task processing and is in the process of trying to execute first steps in the Sweet Home 3D tool.

Here, all group members are actively engaged in the task (= high-quality BE) and show constructive interaction (= high-quality SE). In addition, the group coordinates task processing together, albeit on a rather superficial level (= moderate-quality CE). However, CC was low in this sequence, as evidenced by the fact that the group does not link the individual ideas and does not use any resources to make progress in the task. Rather, the group members are communicating how to use the digital tool and how it works, e.g., from minute 00:16:08, when P1 asks how to draw a map of the area, P2 does not know and suggests simply not do it, and P3 is not sure either and agrees.

**Table 13** Case illustration of selected example sequence with low-quality CC

| Time | | Verbal communication |
|---|---|---|
| 00:16:02 | P1: | Thanks. So here… |
| 00:16:08 | P1: | Can't you enter the area somewhere? |
| 00:16:13 | P3: | Um, I'd say we'll do it without. |
| 00:16:17 | P3: | Okay. Let's do (inaudible) |
| 00:16:20 | P2: | Yes, that's okay. |
| 00:16:24 | P3: | Like that? |
| 00:16:26 | P1: | Thanks. |
| 00:16:27 | P2: | Cool. |
| 00:16:28 | P3: | Okay. |
| 00:16:29 | P2: | And now we will... |
| 00:16:30 | P3: | Now we can actually draw the walls. |
| 00:16:33 | P1: | Do you want to take over again? |
| 00:16:34 | P3: | Okay. |
| 00:16:36 | P2: | You can also move closer if that's more comfortable. |
| 00:16:43 | P3: | Ok so here, right? |
| 00:16:48 | P1: | Yeah. |
| 00:16:52 | P2: | I can't imagine at all what size that actually is. |
| 00:16:55 | P1: | Ahh, exterior walls we also need to draw. |
| 00:16:58 | P3: | Okay. |

Accordingly, there is no nodding, gesticulation, or eye contact in this sequence—this could be because the group is too busy communicating about the tool, which seems to take up the cognitive resources that would otherwise be needed to develop high-quality CC. Interestingly, in this sequence, a low-quality CC does not seem to be unconstructive—the group seems motivated after all and is engaged on the BE, SE, and CE dimension—as the group probably needs this tuning to be clear together about how the tool works so that they can continue to work in a meaningful way afterwards.

## Discussion

In our study, we examined the quality of collaborative group engagement in computer-supported collaborative learning and explored possible relationships with nonverbal group behaviors. We addressed two research questions: First, "Which nonverbal behaviors are indicative of which dimensions of the quality of collaborative group engagement in an authentic computer-supported collaborative learning design task?" Second, "What role do nonverbal behaviors play in sequences of high-quality collaborative group engagement versus sequences of low-quality collaborative group engagement within the four dimensions of behavioral, social, cognitive, and conceptual-to-consequential engagement?"

Regarding research question 1, we found that the frequencies of the following nonverbal behaviors were significantly related to different dimensions of QCGE and thus may be good candidates for QCGE indicators: high frequencies of eye contact, gesturing and pointing, and head nodding are indicative of high SE, CE, and CC qualities. This finding is consistent with literature linking these nonverbal behaviors to mutual reinforcement,

happiness, engagement, and interest, as well as high collaboration quality in social interactions (Behoora & Tucker, 2015; Noroozi et al., 2018; Schneider & Pea, 2014; Wittenbaum, 1999). Our results further show that high frequencies of leaning the upper body forward and resting the chin or cheek on the hand are indicative of high qualities of CE and CC. Regarding leaning forward, the related literature also suggests that this may indicate engagement and interest (Behoora & Tucker, 2015). However, regarding supporting the chin on the hand, related research suggests that it may indicate boredom or frustration (Behoora & Tucker, 2015; Grafsgaard et al., 2014), which is not consistent with our findings—in the groups observed in our study, it may have been more of a "focused supported chin," indicating concentration on the shared task at hand. Furthermore, our results show that high frequencies of laughing and smiling are indicative of high SE quality. This is consistent with related research demonstrating the critical role of positive and responsive nonverbal group behavior in communication and learning (Hovelynck & Peeters, 2003; Hu et al., 2021). Interestingly, in our study, high frequencies of laughing and smiling are indicative of both low BE and CE quality and high SE quality. Thus, we suggest that the role of laughing and smiling in learning groups should be considered in a more nuanced way in terms of individual QCGE dimensions. However, it would be difficult to do this with frequencies and numbers alone—especially given some of the inconsistencies reported above—and this points to the importance of our qualitative analysis, which enrich the quantitative results by adding answers to the question of how exactly the relationships reported above might look. The qualitative results also allow us to discuss our second research question regarding the role of nonverbal behaviors in high- and low-quality QCGE cases, as described in the following sections.

### Behavioral engagement: Having fun despite distractions

High-quality BE sequences were characterized by active group members who demonstrated intense involvement in the task. These sequences exuded a serious and focused atmosphere with much task-related discussion and a focus on the shared screen with minimal laughing or smiling. Conversely, low-quality BE group behavior was marked by either relaxed off-task conversations or a blend of superficial tool usage and cheerful interactions, accompanied by frequent laughing and smiling. Interestingly, unproductive collaborative processes, such as the "free rider effect" (Salomon & Globerson, 1989), were not found within the low-quality BE. Notably, the group's distracted but relaxed and pleasant manner within the low-quality BE sequences seemed to have a positive impact on the collaborative atmosphere. This is consistent with recent research, such as Rogat et al. (2022), who found that, while high levels of QCGE can be expected to lead to more productive collaboration, there may be exceptions, such as occasional off-task joking (low-quality BE), which promotes group cohesion as is suggested, too, by our quantitative findings on high-quality SE as reported above.

### Social engagement: How nodding and laughing contribute to a trusting atmosphere

High-quality SE sequences were observed to be characterized by positive, friendly, and inclusive interactions that cultivated an environment of trust and motivation. Frequent instances of laughing, smiles, and head nodding played a pivotal role in reinforcing

positive group dynamics, sometimes spreading contagiously. These nonverbal behaviors reflected the high responsiveness associated with high-quality SE, in line with previous research (Barron, 2003; Rogat & Adams-Wiggins, 2015). Laughing and smiling, signifying enjoyment (Behoora & Tucker, 2015), contributed to the establishment of a trustworthy atmosphere that is crucial for high-quality SE (Sinha et al., 2015). Thus, laughing and smiling arguably seem to serve a different function for SE than they do for BE, but they promote a relaxed and pleasant atmosphere in both dimensions. However, seemingly unconstructive collaborative processes were found, albeit rather rarely, in the low-quality SE sequences: In these sequences, we identified more dominant group members who failed to acknowledge the contributions of a more reluctant group member, while the more reluctant group member allowed the dominant group member to prevail. This phenomenon could be attributed to the partner dominance effect (Schneider et al., 2018), indicating a social imbalance within the group process. Another pattern of interaction within the low-quality SE sequences was a parallel focus on the screen with individual rather than group effort with one active and two rather unresponsive group members. Accordingly, there was minimal head nodding, laughing, or smiling, reflecting the low responsiveness and thus mixed group cohesion in these sequences, as noted by Sinha et al. (2015).

### Cognitive engagement: Gesturing and aligning with each other as a facilitator for mutual understanding

The use of shared regulatory strategies, such as active planning and coordination and the development of mutual understanding, was associated with sequences characterized by high CE. This was accompanied by frequent gesturing or pointing and leaning forward. These nonverbal behaviors, which according to recent research (Husebø et al., 2011; Grafsgaard et al., 2014; Behoora & Tucker, 2015) indicate engagement and interest and support the achievement of mutual understanding, facilitated joint task coordination and information integration in these learning groups. For example, leaning forward served to align with another group member to show engagement in joint task regulation, and pointing to the shared screen or another group member while making suggestions or adjustments for further task processing served to support mutual understanding. Low-CE sequences, on the other hand, had two predominant characteristics: unfamiliarity with the tools and focused and spontaneous task execution without planning or coordination, reflecting the lack of regulatory strategies within the groups, as described by Sinha et al. (2015). In both cases, participants seemed less interested and motivated, which in turn was underscored by little or no gesturing or pointing and leaning forward.

### Conceptual-to-consequential engagement: Making connections between ideas and between each other

High-quality CC sequences showed that group members actively used resources and connected ideas to solve the task. In addition, they used conceptual tools such as disciplinary practices and domain-specific content, that is, their acquired knowledge about the SH3D tool and architectural psychology. Notably, eye contact, known to enhance collaboration quality and learning outcomes (Schneider & Pea, 2014; Schneider et al., 2018), appeared to facilitate connections between group members, positively impacting CC. Gesturing or

pointing, also associated with high-quality CE, seemed to serve a similar function for CC, supporting mutual understanding, which aligns with prior research (Husebø et al., 2011). Head nodding, which is also related to high-quality SE, also seemed to have a motivating and reinforcing function for CC: It supported and reinforced group members while meeting the demands of integrating ideas, using resources and tools to solve the collaborative task. Low-CC sequences, in contrast, often mirrored low-CE sequences, as groups focused primarily on superficial tool use rather than resource utilization or connecting information or ideas. Nonverbal behaviors were minimal in these sequences, reflecting the superficial execution-centered nature of these interactions.

## Implications

Our findings suggest several theoretical implications. Previous research on QCGE has pointed out that the dimensions of QCGE are interrelated (Sinha et al., 2015; Rogat et al., 2022). For example, Sinha et al. (2015) found that high-quality task planning and monitoring (i.e., high-quality CE) is a prerequisite for high-quality CC. Our current results support these findings: Although the dimensions in our study are mostly very weakly correlated with each other (Fig. 5), the two dimensions CE and CC show a moderate correlation (Spearman's $\rho = 0.38$), suggesting a mutual influence. Furthermore, we observed similar positive functions of nonverbal behaviors in the qualitative case analyses of CE and CC sequences: For example, gestures and pointing, which correlated with both high CE and high CC, seemed to be important for building mutual understanding of the shared task (i.e., high-quality CE) as well as for making connections between group members and their ideas (i.e., high-quality CC). In addition, low-quality CE and CC sequences often mirrored each other, with superficial tool use on the one hand but operational progress on the other. This provides support for Sinha et al.'s (2015) suggestion that CC, as a newly conceptualized engagement dimension, evolves to a high quality level as a function of when CE is also at a high level.

Another theoretical implication related to the dimensions of QCGE that we consider worthy of discussion is supported by our analyses of nonverbal behaviors: As Sinha et al. (2015) noted, the two dimensions of BE and SE can discriminate groups that exhibit low-quality QCGE, whereas CE and CC are needed to explain high-quality QCGE. In our study, low-quality BE sequences did not involve unproductive collaboration, such as free riding (Salomon & Globerson, 1989); in fact, there was often laughter and joking. This suggests that low-quality BE phases may be important for groups to promote other aspects of collaboration, such as high-quality SE. However, we found unproductive collaboration, such as partner dominance (Schneider et al., 2018), in low-quality SE sequences, indicating the need for regulation to establish a foundation for successful collaboration. This is consistent with related research suggesting that cohesive and respectful social interactions facilitate shared sense-making and understanding (Dillenbourg et al., 2009; Van den Bossche, 2006), in contrast to low-quality social interactions that may lead to inequality (Salomon & Globerson, 1989). On the other hand, the CE and CC dimensions were also of low quality in sequences where groups focused on individual steps of the design tool. Although group members sometimes appeared unmotivated or disinterested during these phases, as reflected by low frequencies of related nonverbal behaviors, progress was being made in performing individual, albeit superficial, steps of the shared task—and the absence of nonverbal behaviors could also indicate a shared state of focus. This suggests that high-quality

CE and CC, as well as high-quality BE (as discussed above), are not always necessary, but may be required at certain stages of collaboration and not at others, underscoring the contextualized and dynamic nature of QCGE (Sinha et al., 2015).

This brings us to the issue of learning regulation, as the results we found are closely related to seminal work on temporal and sequential patterns in learning regulation in CSCL (e.g., Järvelä et al., 2016; Malmberg et al., 2017; Vuorenmaa et al., 2022). For example, Malmberg et al. (2017) suggest that CSCL groups are particularly involved in planning and monitoring in the initial phases of collaboration, then increasingly in task execution and planning, and then again in planning and monitoring in the final phases. In addition, individual (i.e., self-regulated) and collaborative (i.e., socially regulated) task monitoring steadily increases from the initial to the final task phases. For our findings, this might imply that CE is particularly important in the initial and final task phases, when planning and monitoring are central, but less critical in the middle phase, when task performance becomes more important. However, in the final phase, according to Malmberg et al. (2017), CE may once again become more important, as planning and monitoring activities become more critical once again. Thus, the notion of Sinha et al. (2015) that CE and CC are required to explain high-quality QCGE can be nuanced with a contextualized perspective, supporting Rogat et al.'s (2022) observation that certain low- or moderate-quality sequences of certain QCGE dimensions in certain collaboration phases may be beneficial for other aspects, such as group cohesion (high-quality SE) or operational progress, as shown in this study.

However, regarding our interpretations related to different phases of task performance, we should remain cautious because a complete and detailed sequential analysis is beyond the scope of this article. Future research that systematically analyzes fluctuations in QCGE or sequential patterns in QCGE dimensions (and how they relate to nonverbal behaviors) will be a useful follow-up research goal. For example, it would be interesting to examine whether sequences of low BE, which our results suggest may be conducive to the formation of high-quality SE, are related to sequences of high-quality SE, or at which stages CE and CC are particularly important and at which stages less so.

Our findings also point to an interesting issue for discussion and future research regarding the relationship between QCGE and learning outcomes. In our study, we did not find significant correlations between QCGE and learning outcomes. This may be due to methodological aspects, e.g., the fact that we evaluated and graded the group products at only one point in time (at the end of the group processes), which resulted in only 38 data points (i.e., grades). In comparison, we assessed the QCGE dimensions every minute, and thus continuously, resulting in 2617 ratings that reflect the entire course of the group processes. In this context, it can also be argued that such complex aspects of group processes in CSCL, such as collaborative group engagement, are unlikely to have a linear relationship with learning outcomes measured at the end of the process. Thus, in line with the finding discussed above that some QCGE dimensions seem to be important in certain phases and not in others and consistent with the conceptualization of QCGE as dynamic and contextualized, the equation that high engagement leads automatically to high learning outcomes is probably too simple. It is possible that other important aspects of learning outcomes, such as transfer performance or individual learning gains, which were not measured in this study, may also be related to QCGE. It would therefore be interesting for further research to measure the performance of student groups more comprehensively, for instance also sequentially, in order to draw more meaningful conclusions about the relationship between QCGE and learning outcomes.

In this context, we refrain from deriving practical implications from our results for CSCL design. At this point and regarding the complex relationship of QCGE and learning

outcomes and given that we investigated QCGE in an experimental setting (see "Limitations" section), further investigation on this topic is needed before we can draw any conclusions with regard to practice. Thus, we can only derive some initial issues for practice-related future research. For instance, it might be interesting to investigate QCGE in real classroom settings or possible influences of QCGE teacher knowledge on lesson planning and teaching. Furthermore, it would be instructive to explore how nonverbal behaviors could be used as indicators of high- or low-quality engagement for the development of real-time QCGE analysis and feedback systems (cf. Deeva et al., 2021), which as described above, is a promising approach for fostering collaborative group engagement and learning outcomes (Zheng et al., 2023).

## Limitations

Of course, our research is not without its limitations. From a methodological perspective, one limitation is the low variance in the QCGE ratings of the BE and SE dimensions. We suspect that this is partly due to the laboratory setting and the short task duration. Although the laboratory setting allowed us to adequately control our research variables, we suggest that future studies examine nonverbal behavior in relation to different dimensions of QCGE in realistic field settings. In addition, it is possible that task design and the instructions (high versus low structuring, see "Methods" section) played a role in motivation, for instance influencing the low variance in BE and SE. The task was well designed, and students seemed motivated to comply with the experimental situation. Therefore, future research would be useful to examine the relationships between QCGE and nonverbal behavior within tasks with different motivational potentials (cf. Heinle et al., 2022).

Another limitation lies in the coding and rating by human coders. Careful rating, coding, and counting is always very laborious, and some degree of human bias can never be ruled out (cf. Hoyt & Kerns, 1999). Therefore, current developments in the field are increasingly moving toward automated coding and rating (e.g., D'Mello et al., 2017; Zheng et al., 2023), which will certainly minimize this bias. Such methodological approaches are promising for future studies of the relationship between QCGE and nonverbal behavior and are currently being explored in our research efforts (Jeitziner et al., 2024). Additionally, it is essential to note that, in our analysis, we consistently interpreted nonverbal behavior also within the context of verbal behavior (i.e., the QCGE rating scheme). This was a deliberate decision based on the feasibility and accurateness of the coding and rating procedures and in recognition of the complexity of group processes in CSCL. It would be valuable to analyze QCGE while incorporating additional factors, such as self-assessments, to explore how nonverbal behavior correlates with engagement in CSCL.

Finally, it is important to note that the results are tied to a specific study context and therefore should be applied with caution to other situations (e.g., younger students in primary or secondary education) or cultures. While we identified significant nonverbal indicators of certain dimensions of QCGE, these nonverbal behaviors may indicate different aspects in other situations or settings or with other samples. Or, as Patterson et al. (2023) state, "NVC [nonverbal communication] is the product of multiple cues and behaviors" (p. 15), meaning that nonverbal behaviors can never be unambiguously indicative of very specific internal states or aspects of collaboration, but rather can provide clues about them in relation to specific contexts and should therefore be considered in a nuanced way. For

example, culture, the relationship between the participants, and gender are important moderators when it comes to the interpretation of nonverbal behavior (Burgoon & Dunbar, 2018), which we did not explicitly include as control variables in our analyses. Therefore, more research that examines QCGE and nonverbal behavior in different contexts and settings is needed.

## Conclusions

The findings of this study elucidate the nuanced relationships between QCGE dimensions and nonverbal behaviors in CSCL. Methodologically, our approach of systematically integrating nonverbal behaviors into case illustrations that zoom in on sequences of verbal and nonverbal group interactions in CSCL provides a novel means of representing and qualitatively analyzing engagement within a shared, multifaceted, dynamic, and contextualized framework. Our study also allowed us to further develop the QCGE rating scheme originally introduced by Sinha et al. (2015), refining and adapting it to a particular CSCL setting involving higher-education learning groups in a laboratory setting. In addition, our custom coding scheme for nonverbal behaviors proved to be a valuable tool. These methodological refinements will allow future researchers to apply them in additional research settings. From a theoretical perspective, our findings shed light on specific relationships between nonverbal behaviors and QCGE, as well as the particular role that nonverbal behaviors play in sensing QCGE dimensions. In particular, they highlight the dynamic and contextualized nature of QCGE: our results show that collaborative group engagement is not a fixed state that is either high or low and thus leads to either success or failure, but that it plays a different role depending on the context and phase of the collaboration. These new original findings extend the QCGE construct and thus contribute to a deeper understanding of collaborative group engagement in the context of CSCL.

**Supplementary information** The online version contains supplementary material available at https://doi.org/10.1007/s11412-024-09422-7.

**Acknowledgements** This research was supported by the Swiss National Science Foundation under National Research Program 77 and Research Project No. 407740_187258, by the University of Applied Sciences Northwestern Switzerland, School of Applied Psychology and the University of Basel, Faculty of Psychology. Furthermore, we would like to thank all the students who participated in this study and those who agreed to allow us to use screenshots of their video material for illustrative purposes.

**Author contributions** Lisa Paneth: Conceptualization, Investigation, Qualitative Methodology, Writing-Original draft preparation, Data Curation. Loris Jeitziner: Conceptualization, Investigation, Quantitative Methodology, Writing- Original draft preparation, Data Curation. Carmen Zahn: Conceptualization, Writing - Review & Editing, Supervision. Oliver Rack: Conceptualization, Writing - Review & Editing, Supervision. Klaus Opwis: Writing - Review & Editing, Supervision.

**Funding** Open access funding provided by FHNW University of Applied Sciences and Arts Northwestern Switzerland Schweizerischer Nationalfonds zur Förderung der Wissenschaftlichen Forschung, 407740_187258

**Data availability** The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

## Declarations

**Conflict of interests** The authors declare no competing interests.

**Ethics vote** The study was approved by the ethics committee of the School of Applied Psychology, University of Applied Sciences and Arts Northwestern Switzerland. Approved application number: EAaFE200622a. Written informed consent was obtained from the participants who appear in the screenshots of video footage captured as part of this study.



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