Chapter 16
Collaborative Learning in College Science: Evoking Positive Interdependence

Karin Scager, Johannes Boonstra, Ton Peeters, Jonne Vulperhorst, and Fred Wiegant

Working in groups provides opportunities for students to practice and further develop twenty-first-century skills, including cooperation, scientific reasoning, critical thinking, communication, and problem-solving but also to learn more effectively (Slavin 1991, 2014). All these are relevant skills that prepare students for future jobs as they will often find themselves to be part of small group work (Theobald et al. 2017). Teamwork is highly important in the workplace where products and tasks are increasingly complex, requiring expertise from various individuals with a variety of skills and knowledge. As teamwork has become more prevalent, employers are more frequently looking for job candidates with a demonstrated ability to work in teams. In a survey of 260 organizations, employers rated teamwork as the most important quality in recruits (Theobald et al. 2017).

In general, group work is known to encourage students to construct their own understanding of scientific topics and concepts through a process of academic discussion and consensus building with their peers (Solomon 1987). Although students may learn more effectively from working in groups as opposed to individual learning, the learning potential of collaboration seems to be underused in practice (Johnson et al. 2007, 2014), particularly in science education (Nokes-Malach and Richey 2015). Collaborative, cooperative, and team-based learning are usually considered to represent the same concept, although they are sometimes defined differently (Kirschner 2001); we consider these concepts comparable and use the term "collaboration" throughout. In collaborative learning, students participate in small group activities in which they share their knowledge and expertise. In these student-driven activities, the teacher usually acts as a facilitator (Kirschner 2001). Several decades of empirical research have demonstrated the positive relationship between

K. Scager (✉) · J. Vulperhorst
Department of Social Sciences, Utrecht University, Utrecht, The Netherlands
e-mail: k.scager@uu.nl

J. Boonstra · T. Peeters · F. Wiegant
Department of Biology, Utrecht University, Utrecht, The Netherlands

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collaborative learning and student achievement, effort, persistence, and motivation (Slavin 1980, 2014; Webb and Palinscar 1996; Barron 2000; Johnson et al. 2007, 2014). Collaborative learning potentially promotes deep learning, in which students engage in high-quality social interaction, such as discussing contradictory information (Visschers-Pleijers et al. 2006). In science education, a deep-learning approach is crucial for understanding concepts and complex processes (Van Boxtel 2000). Understanding of these concepts involves a process of conceptual change, a process particularly activated in collaborative learning, whereby students interact by explaining to and questioning one another critically (Van Boxtel et al. 2000; Linton et al. 2014).

There are various reasons why collaborative learning is highly relevant and should be integrated into courses. Collaborative groups increase learning, cultivate positive attitude toward science and stimulate one's identity as a scientist (Tanner et al. 2003; Johnson et al. 2014; Theobald et al. 2017).

Previously we have explored and documented the importance of collaborative learning in undergraduate biology (Wiegant et al. 2012, 2014). By comparing biology student achievement in individual and group settings, Linton et al. (2014) found that students in group settings achieved significantly better conceptual understanding in comparison to those enrolled in courses in an individual setting.

Just forming groups, however, does not automatically result in better learning and motivation (Salomon and Globerson 1989; Gillies 2004; Khosa and Volet 2013). In their study of university students' preferences, Raidal and Volet (2009) found an overwhelming preference for individual forms of learning. Students are hesitant about group work because of the occurrence of "free riders," logistical issues, and interpersonal conflicts (Livingstone and Lynch 2000; Aggarwal and O'Brien 2008; Pauli et al. 2008; Shimazou and Aldrich 2010; Hall and Buzwell 2012). As a result, students often opt for a strategic approach by dividing the work and merely using a stapler to "integrate" their work into a group paper. Johnson and Johnson (1999) refer to groups showing this kind of superficial behavior as "pseudo learning groups." In turn, the resulting lack of synthesis can be disappointing for teachers. Dividing work also implies that students lose the potential learning effect of collaborating, since the extent to which students benefit from working with each other depends on the quality of their interactions (Van Boxtel et al. 2000; King 2002; Palincsar and Herrenkohl 2002; Volet et al. 2009; Chang and Brickman 2018). Chang and Brickman (2018) conducted in-depth interviews with students to identify student perceptions of factors that explain the differences between high-performance and low-performance groups. The three factors most frequently mentioned were *individual accountability* (other students have done their part); *cognitive learning support by peers* (engaging in a dialogue with peers to explain difficult concepts); and *procedural support by peers* (helping each other to finalize a task, to make decisions, or to meet deadlines). However since these factors were both considered relevant by low- as well as high-performance groups, they could not be used to distinguish between the performance level of these groups. In this chapter we explore factors that were reported to optimize the quality of collaboration, using examples of effective group work in five different life sciences courses.

Potential Factors Enhancing the Effectiveness of Collaborative Learning

Social interaction is crucial for effective collaboration (Volet et al. 2009). Learning outcomes of collaborative learning groups have been found to depend on the quality of student discussions, including argumentation (Teasley 1995; Chinn et al. 2000), explaining ideas to one another (Veenman et al. 2005), and incorporating and building on one another's ideas (Barron 2003). These interactions with peers are assumed to promote students' cognitive restructuring (Webb 2009). Explaining things to one another and discussing subject matter may lead to deeper understanding, recognition of misconceptions, and the strengthening of connections between new information and previously learned information (Wittrock 1990). The question of how to organize collaboration in a way that promotes these kinds of interactions is paramount.

Decades of research on group work have resulted in the identification of various factors that potentially enhance the effectiveness of collaboration. These factors can be differentiated as primary factors or design characteristics and secondary, mediating factors or group process characteristics. Regarding primary factors, *groups need to be small* (three to five students) to obtain meaningful interaction (Lou et al. 2001; Johnson et al. 2007). With respect to group composition, *mixed-ability* groups have been found to increase performance for students of lower ability, but this composition does not necessarily benefit high-ability students (Webb et al. 2002). *Equal participation*, however, has been shown to be more important for students' achievement than group composition, because students are more likely to use one another's knowledge and skills fully when all students participate to the same extent.

The nature of the task has been shown to be an important factor as well. *Open and ill-structured tasks* promote higher-level interaction and improve reasoning and applicative and evaluative thinking to a greater extent than closed tasks (Gillies 2014). In addition, complex tasks provoke deeper-level interactions than simple tasks (Hertz-Lazarowitz 1989).

Concerning secondary or intermediate factors affecting group work, positive interdependence theory is one of the best-founded theories explaining the quality of interaction in collaborative learning (Slavin 1980, 2014; Johnson and Johnson 1999, 2009; Johnson et al. 2014; Gully et al. 2002). According to this theory, collaboration is enhanced when positive interdependence exists among group members. This is achieved when students perceive the contribution of each individual to be essential for the group to succeed in completing the assigned activity (Johnson and Johnson 2009). Positive interdependence results in both individual accountability and promotive interaction. Individual accountability is defined as having feelings of responsibility for completing one's own work and for facilitating the work of other group members. A sense of mutual accountability is necessary to avoid free riding (Johnson and Johnson 2009), which occurs when one or more group members are perceived by other members as failing to contribute their fair share to the group effort (Aggarwal and O'Brien 2008). Promotive interaction has been described as students

encouraging and facilitating one another's efforts to accomplish group goals, both with respect to group dynamics and the subject matter (Johnson and Johnson 2009; Johnson et al. 2014).

Methods of inducing positive interdependence are either reward or task based (Johnson et al. 2007). Reward-based interdependence structures the reward in such a way that students' individual grades depend on the achievement of the whole team. According to Slavin (1991, 1995, 2014), collaborative learning is rarely successful without group rewards. However rewards that stimulate extrinsic motivation (grades) may be detrimental to intrinsic motivation (Parkinson and St. George 2003). Intrinsically motivated students put effort into a task because they are interested in the task itself, while extrinsically motivated students are interested in the reward or grade (Deci and Ryan 2000). Strong incentives, such as grades, could steer student motivation toward the reward and subsequently reduce the task to being a means to an end.

In structured task-based interdependence, students are forced to exchange information; this can be achieved by assigning group members different roles, resources, or tasks (the "jigsaw" method) or by "scripting" the process, which involves giving students a set of instructions on how they should interact and collaborate (Kagan 1994; Dillenbourg 2002). The effects of task structuring on collaborative learning are not completely clear (Fink 2004; Hänze and Berger 2007; Serrano and Pons 2007). For example, Hänze and Berger (2007) observed no differences in achievement between students who worked in jigsaw-structured groups and students who worked individually while Brewer and Klein (2006) found that students in groups with given roles and rewards interacted significantly more frequently than students in groups with given rewards only or in groups with given roles only. Although positive interdependence has been shown to be crucial in evoking social interaction, in practice university students often choose the solution requiring the least effort, explaining why positive interdependence often does not emerge (Salomon and Globerson 1989).

Despite considerable research on collaborative learning, little is known about how to structure university-level group work in order to capitalize on this instructional method. In our study, we approached the issue retrospectively, investigating the learning of student groups known to have collaborated and achieved highly (Scager et al. 2016). Rather than focusing on learning outcomes, we explored how group work in these courses was structured. In so doing, we explicitly explored positive examples of effective collaborative learning, thereby identifying those critical factors that enhance learning through student collaboration (Dewey 1929).

Participants

Our research involved focus group interviews with nine groups of second- and third-year students of five different undergraduate life sciences courses of Utrecht University. They allowed us to gain insight into students' perspectives, which is

important because, to a large degree, students' perspectives of instruction affect what they do and learn (Shuell 1996). The particular courses were selected because they all implemented group work that was very effective. We approached the instructors of these courses with the request to ask their students to volunteer in focus group discussions. Between three and ten students participated in each of the nine focus group interviews (Scager et al. 2016).

Course Descriptions

We focused on five small-enrollment, upper-division courses each of which enrolled 15–35 students. In all courses, collaborative activities occurred during class hours but also outside of class. In some courses, the out-of-class cooperative activities even exceeded the in-class activities.

Course A: Honors Biology (Wiegant et al. 2012; Peeters and Wiegant 2019). Groups of second-year students (n = 12–19) were assigned the group task of writing a popular science book about a biology topic of their choice. Students had to perform all the activities necessary to produce the book. The project was strongly student-led, and students assigned themselves tasks necessary for finishing the project. The assignment comprised an entire academic year, starting in September and finishing in May/June as an extracurricular activity. Three group interviews were done with an average of six students per group.

Course B: Immunology. Third-year students were assigned in groups of four the task of writing a short research project on an immunological topic. The assignment was structured in three parts: groups designed a draft of their proposal; groups peer reviewed the draft of another group, and groups received the draft and comments of yet another group, which they had to finish and present. The assignment comprised approximately half of the course. Two group interviews were done with five students per group.

Course C: Advanced Cell Biology (Wiegant et al. 2011, 2014; Scager et al., 2014). Three small teams of four or five students each collaborated intensively during a semester to formulate Ph.D. proposals within an overarching theme. Because the course was student-led, the teachers refrained from guiding the students in their decisions, instead taking a facilitating role by asking critical questions and providing feedback. Subsequently, the teams presented and defended their three research proposals before a jury of experts. One group interview was done with ten students.

Course D: Molecular Cell Biology. Students were required to complete multiple assignments, such as reviewing a paper, developing a research proposal, designing experiments, and writing and defending their proposals. Groups met with their supervisor once a week and were supposed to keep the course coordinator informed of their progress. Final grades were based on individual (40%) and group (60%) components. One group interview was done with three students.

Course E: Pharmacy. Third-year students, in groups of four to six participants, were required to analyze the quality of a specific pharmacotherapy. The assignments were authentic in that they were provided by external commissioning companies. The group assignment counted for 70% of the final grade (50% group report and presentation; 20% individual reflection). Two group interviews were done with six students per group.

Interviews

The interviews were semi-structured and included two basic questions: (1) "What factors made group work effective in this course (as opposed to other experiences you have had)?" and (2) "What was the added value in this course of working in a group (as opposed to working individually)?" The addition of "as opposed to …" was aimed to encourage students' thinking processes; we did not ask students to elaborate on these opposing experiences. Interviewers stimulated and moderated discussions, ensuring depth as well as diversity. To focus and structure the interviews and to stimulate the sharing of discussion outcomes, we listed responses to the two questions on a flip chart. The focus group interviews were held in or near the classroom associated with each of the specific courses. The interviews were 60 min each and were transcribed verbatim.

Factors That Contributed to the Effectiveness of the Collaboration

Several factors were found to have a positive effect on the collaboration. These factors may be labelled (1) *design factors*, the design of the course and/or the assignment (the autonomy of the students, task characteristics, teacher expectations, and group size) and, (2) *process factors*, the way students interacted and organized their work (team and task regulation, interdependence, promotive interaction, and mutual support and motivation).

Design Factors

The *autonomy* that the groups experienced was mentioned in all focus groups, indicating the importance of this factor to the effectiveness of collaboration. Autonomy was manifested in allowing student groups to choose their own topics for their research plans or popular science book, thus giving them independence in organizing their processes. Statements such as "It was our own thing" occurred frequently

in all nine focus group discussions. The references to "our thing" indicate that the students made choices as a group, which could have restricted individual feelings of autonomy. The students, however, did not seem to have experienced clear boundaries between individual and group autonomy. Even though their personal ideas may have been overruled by the team, they still felt autonomous, because they made decisions democratically. As one of the students said, "When you participate in the decision process it is easier to accept than when the decision is made by the teacher."

Two features of the task were perceived as important contributors to the effectiveness of the group work. First, the *density and complexity* of the task was crucial. The group task needed to be extensive enough for the group members to really need one another's contributions to finish in time and complex enough to require them to discuss their work and provide one another with feedback. Second, students perceived the *relevance* of the task at hand to be an important feature. The task relevance was found in different aspects, depending on the assignment. For the Honors Biology groups, for example, the process of writing a popular science book and getting it published increased their feelings of doing something significant. The Cell Biology and Immunology groups emphasized the relevance of doing research, in terms of formulating a relevant proposal in the same way as it is done "in the real world."

In terms of *rewards*, students emphasized that the inherent value of the end product, such as an article, a research proposal, or a book, stimulated them to achieve, which relates back to the perceived task relevance. As an Honors Biology student said, "We have also had other group projects …, but that was taken less seriously, because you, well it was nice, but well, the result wouldn't reach beyond the classroom, while in this project it will." There were no grades involved in this particular course, which students appreciated, because they believed the end product to be more important than a grade. Also, in other groups, discussions about assessment were learning and/or reward oriented rather than grade oriented, for example, in one of the pharmacy groups, it was said: "You are in a learning process, and I think sometimes that it is a shame that it should end in a grade—that creates a tension. And if things go wrong, that could be very beneficial for your learning, but it can also happen that you do not receive a high grade for it."

In all of the interviews, students mentioned that it was crucial that the task was the core project in the course, as an Immunology student stated: "I think also because this is not something you do on the side, but this is the only thing we do at the moment, it is the main activity." The fact that students' final grades depended primarily on the group assignment was mentioned in some groups. Students emphasized that in previous experiences with group assignments they had not collaborated as intensively because their final grade did not depend largely on the team assignment. Finally, *group size* was considered a factor stimulating collaboration in seven of the groups, specifically related to the level of responsibility students felt. Groups of three or four were believed to be optimal: "Otherwise, you get a sort of diffuse responsibility …, and with four you are clearly responsible for an important part of the process."

Process Factors

The need for *team and task regulation* was mentioned most frequently as important process factors in collaboration. Students divided tasks, appointed team leaders, and set their own deadlines. Organizing frequent face-to-face meetings was very helpful, according to students: "That we met each other physically, instead of doing everything by mail or chat, like in other projects. This works much better, if you can look each other in the eyes it is way faster and more efficient to manage and decide things …. It also increases the pressure, everybody prepares for a meeting." In addition, the students acknowledged the direct relation between the autonomy of the groups and their dedication to following their self-made group regulations: "It was important that we made agreements at the start …, for example that we agreed to finish the report a week before the deadline, and about who did what, and what the rules were, these kinds of things." Students in all nine focus groups experienced a sense of *positive interdependence* in terms of needing one another in order to succeed and achieve their goal. The feeling of responsibility was discussed in six groups. The related issue of "uneven contribution" was discussed in all nine of the focus groups, and students did experience differences in power and effort between team members. Interestingly, students did not perceive this as free riding. According to the students, some degree of uneven contribution is only natural; the students all did their best, but as one student said, "There weren't students who contributed less; there were only students who contributed more." According to the students, this uneven contribution was due to power differences, not to disinterest or laziness. Students showed empathy for their peers who contributed less: "The strong people might go too hard for the other people to be able to catch up." This may have caused frustration in students who felt they were lagging behind, as one of them revealed: "You have that responsibility that drives you and then you feel the need to do more, but perhaps that is beyond your capabilities at that point." Some of the groups discussed the issue of uneven contribution while working on their projects, but always, they stated, in an "understanding and respectful way."

Furthermore, students in all nine interviews mentioned that diversity among students was useful and enhanced the discussions: "working in a group consisting of clones of yourself" would not be as interesting, one of the Pharmacy groups stated. In this respect, it is interesting that the students seemed to recognize an important factor in group or collective intelligence (Woolley et al. 2015), which is that heterogeneity is important in support of effective and creative group work.

All nine groups mentioned the need for *promotive interaction* several times, drawing attention to the need to discuss content to accomplish team goals. They mentioned several indicators of promotive interaction: discussions, exchange of information and arguments, building on one another's ideas, explaining to one another, providing and processing peer feedback, and asking one another critical questions. According to the students, these discussions enhanced their understanding, and they also learned how to discuss, voice their opinion, explain, listen to others, accept feedback, and reflect on their own work.

Finally, students talked enthusiastically about the way they *supported and motivated* one another. Several comments suggested the value of explicit help and pep talks as well as the implicit mutual support of their peers. This shared motivation was apparently due to the fact that most students already knew one another: "When you are in your first year, you do not know each other, and some people are a bit insecure, so to say. But now we know each other, so we may scold each other all we can." Furthermore, students suggested being equally motivated, because the unmotivated students had already left in previous years.

Conclusions and Suggestions for Best Practice

The results indicate that positive interdependence was a crucial factor contributing to the effectiveness of collaboration. Students explained the interdependence in terms of the necessity to discuss a variety of aspects of their activities and give feedback on each other's contributions, regulating the teamwork and making mutual agreements, feeling responsible, and the need to support, motivate, and complement one another. The interdependence seems to have been evoked by several factors:

First, the *challenging nature of the task* was important. The tasks in all of the groups were large, as one of the students stated: "I think you also need your group actually, in terms of being able to finish the project, because the project we made was so large, you have to contribute to get it done." *Suggestion*: Assignments for groups should be challenging enough to require that the group members need each other to complete the task in time. For example, problems should be complex, or require multiple perspectives to answer thoroughly, or simply fit the size of the group to the task or the other way around. To evoke positive interdependence, the group task also needs to be central in the course instead of being one of many assignments.

Second, the *tasks must be relevant and authentic*, as one of the students said: "We have written a really cool article … this is much nicer than exams, we now have something useful." The relevance of the tasks, which required students to produce something new (to them) and something original and tangible, motivated students. The tasks were also open and complex, which are features that have already been found to promote deeper-level interactions than simple tasks (Hertz-Lazarowitz 1989; Cohen 1994). Interestingly, these students seemed to value the products they were working on and the learning process more than their grades. *Suggestion*: Design assignments that are relevant to students in which they are able to create results that are important to them. Making the assignments authentic usually helps. For example, by changing their roles from student team to advisory board, editorial board, expert team, or ghostwriters or by changing the product, from writing a paper to producing, for example, a future scenario, a script, a press release, or a thematic issue of a journal.

Third, *allowing students some autonomy over the process* enhanced their responsibility. The enthusiasm of the students when speaking of the way they supported

and motivated one another and regulated the team and task processes indicates the occurrence of strong self-regulatory processes. In contrast to Johnson and Johnson's (2009) recommendation for teachers to structure processes, students in our courses indicated that the autonomy they enjoyed was one of the factors increasing their motivation. Although some structure was provided beforehand in all five courses, students perceived autonomy in the planning and regulation of their work, which added to their motivation to follow their own rules and planning. As one of the students explained: "It's also the independence, that we did everything ourselves, so you feel more responsible." The self-regulatory social processes, encouraged by the autonomy they experienced, were the most important factors increasing the effectiveness of their collaboration in these five cases. In this respect it is of interest that students did not experience "free riding" behavior in their groups. *Suggestion*: Allow students (some) autonomy over the process of task division and deadlines, instead of turning the assignment into a steeplechase. Our findings indicate that students are more inclined to act upon deadlines and agreements they set themselves. Face-to-face communication between team members helped them to deliver in time and remind each other of the promises they made.

Fourth, *ownership* was a frequently mentioned factor contributing to the effectiveness of the group work. Students were proud of their end products, and the autonomy they experienced enhanced that feeling. In describing the effectiveness of their groups, students in our study used the word responsibility: "There's the responsibility, because, when you write an essay individually, when you screw up, the consequence is yours only. But now, you are with a large group, and unconsciously, you have the feeling that it has to be good, because otherwise others will suffer as well." The difference between responsibility and accountability is meaningful, because accountability is focused on the end result, or being answerable for your actions to relevant others, while responsibility is related to the task. Responsibility is viewed as having a higher level of autonomy and involves the ability to self-regulate actions free of external pressure. In contrast, the accountable actor is subject to external oversight, regulation, and mechanisms of punishment (Bivins 2006). The term "responsibility" more appropriately fits the collaboration in these cases, as one of our participants illustrates: "You feel the responsibility to other people in your group, because as soon as you drop the ball, the rest have to work harder." This student does not refer to consequences externally imposed on him, but he feels responsibility toward others. *Suggestion*: Allow students (some) ownership over their results. When they are working toward something to be proud of, it needs to be the result of their own effort. To maintain student's ownership, teachers need to stay clear of steering too strongly. Asking critical questions that stimulate students to find their own answers could be sufficient. Another way to validate their work is to direct students to other sources or experts in the field.

Fifth, by allowing students autonomy the teacher demonstrates *trust in their ability and their willingness to learn* and make an effort. Active learning can only occur when two basic factors are met: (1) the students will make the effort on their own, and (2) teachers express trust in them to do so. Being engaged in active learning is demanding and challenging for students, especially when they find themselves

adrift in a sea of information. To foster active learning, teachers must not only trust their students but also express trust in their competencies to accomplish the complicated and challenging task. Likewise, students must trust their teacher to facilitate the process or assist when necessary (Adams et al. 2017). *Suggestion*: Try to evoke positive interdependence rather than enforce it by (over)structuring. We found that trust in students' willingness to learn was more effective than control. Students also need to trust each other. The fact that they trust each other was illustrated by students not perceiving the ones who do less as free riders. The groups we studied knew each other and did not need much guidance on the collaboration process. However, other groups might need more help, for example, by asking the teams at the start of the process to discuss their goals, ambitions, and their personal strengths and weaknesses that their peers should know about. They could also discuss the ground rules they want to set for their group.

Although autonomy and challenging assignments appear to be vital for teamwork, instructors in different settings may need to use greater scaffolding. Autonomy increases the level of challenge even further. If challenge exceeds perceived skills, students can get worried and anxious, which reduces feelings of flow and intrinsic motivation (Csikszentmihalyi 1975; Deci and Ryan 1985; Pekrun 2006). Although this may be the case for individual students, when working in groups, students may help or support each other preventing negative emotions at the group level. Nevertheless, it is important to keep an eye on the balance between the level of challenge and the perceived level of ability. *Suggestion*: To support students' perceived level of ability, the feeling that they are able to complete the task at hand, it helps to tell them in advance that the task will be difficult, or let them know that it is only normal to face problems on the way. Another way to help is to create a safe atmosphere, in which it is okay to get stuck or to make mistakes. Further, make sure that students know that you are available if they need help.

Concluding Remarks

In this study, we focused on best practices in collaborative work, finding a set of factors that were supportive of positive interdependence and enhanced learning. It is important to keep in mind the small sample and restricted context when interpreting these findings. Although the results have been obtained in small-enrollment, upper-division courses, we think that our findings might also be transferable to large-enrollment courses, provided students are working in self-directed small groups on substantial and relevant projects. According to Berliner (2002), implementing scientific findings is always difficult in education, "because humans in schools are embedded in complex and changing networks of social interaction." Therefore, we do not claim to have produced broadly generalizable findings but instead invite the reader to identify how the findings can be transferred to his or her situation. Similar studies with data from other university contexts would help in understanding how the conditions that facilitate collaborative learning relate to different settings. We

believe that the concept of "evoking," rather than enforcing, positive interdependence provides relevant insights for effective design of group work within the life sciences. Students at the university level can be assumed to be experienced in working in groups and in regulating their own work. In this study, autonomy and trust in students provided by the teacher, combined with a challenging task, evoked interdependence, generated positive interdependence and prevented free riding. We suggest that there is value in designing challenging and relevant tasks that build shared ownership between students, in combination with relying on trust in students rather than controlling their actions, trust in their willingness to learn and to collaborate, to fully implement the conditions to foster positive interdependence in collaborative learning.

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