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Promoting and Managing Student-Student Interactions in Online STEM Classes*

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The power of collaborative activities to improve students' learning, curricular retention, self-efficacy, and attitudes toward their instruction in face-to-face college classes is well supported by research. Whether the instruction qualifies as active learning, collaborative or cooperative learning, or an inductive approach such as inquiry-based, project-based, or problem-based learning, as long as the collaborations follow research-validated guidelines, the students on average outperform students taught entirely with lectures and individual assignments. A smaller but still substantial body of research shows similar benefits for online collaborative activities, but questions remain regarding the effectiveness of such activities and how best to implement them. This paper outlines synchronous and asynchronous online collaborative activities suitable for STEM courses, surveys research on the impacts of such activities on students' learning and attitudes, suggests effective implementation strategies, and offers recommendations for additional research.

Keywords: active student engagement; cooperative learning; discussion boards; online

1. Introduction

Online courses make up a large and growing segment of university-level instruction. Even before the COVID-19 pandemic erupted early in 2020 and caused universities to abruptly switch most of their instruction from face-to-face (F2F) to online, millions of college students were taking many of their classes online for reasons of cost or convenience. The pandemic quickly made the question of how to teach effectively online a central concern of teachers at all levels worldwide.

The power of interactive student engagement to promote almost every conceivable student learning and attitude outcome in F2F courses has been well established in hundreds of research studies [1, 2], and research has also confirmed the powerful impact of student-student interactions on online students' performance in and satisfaction with their courses [3–6]; [7, pp. 131–164, 228–229]. A particularly valuable attribute of student-student interactions is their power to instill *social presence* – students' feeling that their classmates are real people who are potential sources of cooperation and support. A lack of social presence in online courses can burden students with a demotivating sense of isolation, which may in turn contribute to the greater incidence of dropouts observed in online courses than in F2F courses [8–12].

In a recent article, we outlined strategies for actively engaging STEM students with course content, instructors, and classmates in synchronous and asynchronous online courses, and we reviewed research on the effectiveness of those strategies [13]. In the same paper, we discussed the recently coined distinction between routine online teaching and "emergency remote teaching" (instruction in an F2F course that has abruptly been shifted online) [14, 15], and we summarized findings regarding teaching strategies that substantially raise student satisfaction with online instruction in both categories [16, pp. 14–15].

This paper examines online student-student interactions in greater depth, shifting the focus more toward courses in which the students either interact with one another entirely asynchronously or occasionally meet synchronously in small groups to work on team assignments or projects. After suggesting a variety of possible interactions, we focus on two particularly powerful asynchronous approaches – *discussion boards* and *online cooperative learning.* Discussion boards (also known as *discussion forums*) are often the primary vehicle for asynchronous online student-student interactions. With a suitable level of instructor direction and active student participation, they can be used to help students develop skills in high-level analytical problem solving, creative and critical thinking, and communication. Cooperative learning has also repeatedly been shown to promote those skills as well as high-performance teamwork skills in F2F courses, and recent research suggests the likelihood of obtaining similar results in online courses. The paper concludes with general recommendations for

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maximizing the effectiveness of whichever strategies are used to obtain online student collaboration, followed by recommendations for future research.

2. What Can Online Students Be Asked to Do Collaboratively?

Table 1 presents a list of collaborative online activities. Activities labeled *S* can be carried out in synchronous class sessions by small groups of students via private chats or in breakout rooms. Those labeled *A* can be done using asynchronous discussion boards or by student teams whose members share documents and have occasional synchronous meetings.

3. Making Synchronous Online Collaboration Effective

Standard recommendations for making small-group collaborative activities effective in F2F classes [18, Ch. 6] also apply to synchronous online classes.

- *Make activities challenging enough to justify the time it takes to get into groups and establish*

Table 1. Collaborative asynchronous (A) and synchronous (S) online course activities

Activity	**A or S**
Answer questions. If a question is straightforward, don't make answering it a group activity; just ask it, tell the students to raise hands (physically or virtually), and call on one or more to respond. If it is open-ended, again use hand-raising or ask the students to submit answers in chat, and if the question is particularly challenging, send the students to breakout rooms to figure out the answer. Consider giving cooperative pre-exam team quizzes.	S
Make up questions. Put students in pairs and give them a short time to make up one or two nontrivial questions about recent class content. (This is an excellent activity for classes in which the same two or three students tend to ask all the questions.) The students may generate their questions in private chats with designated partners or in breakout rooms.	S
Solve problems, derive formulas. In a synchronous class session, have students in breakout rooms start a challenging problem solution or derivation or work out the next step. If the course is asynchronous (no synchronous class sessions), the interactions may occur in synchronous student team sessions, ideally following the tenets of cooperative learning. Details for both synchronous and asynchronous classes are outlined in later sections.	A, S
Think-pair-share. Students in a pair individually respond to a prompt (e.g., answer a question, explain a concept in terms a nonexpert could understand, interpret an experimental outcome). They then work together in a private chat or breakout room to share their responses and attempt to synthesize an improved response.	S
Peer instruction. Individual students vote on the answer to a ConcepTest (a multiple-choice conceptual question with distractors that include common student misconceptions), form pairs and try to reach agreement on the correct answer, and revote [17]. A *poll* is an excellent online tool for administering ConcepTests.	S
Brainstorm. List [*possible designs of a process, product, or procedure; possible reasons why a proposed process, product, or procedure might fail or a problem solution or derivation or output of a computer program might be wrong; possible real-world applications of a specified theory, design, formula, or experimental result*]. Making the activity competitive with a nominal prize going to the team with the longest list can raise the energy level of a class for this type of activity. Brainstorming followed by selection and prioritization of ideas (next row) helps students develop both creative and critical thinking skills.	S
Select, prioritize. Given a list of alternatives, using a specified criterion (e.g., most likely, most feasible, most economical, safest, most environmentally sound, most creative) or a specified combination of criteria, select the best item on the list or the top three or top 10 items in priority order, and justify the selection(s).	A, S
Thinking-aloud pair problem solving (TAPPS). A member of a pair explains or works out a step in a derivation or problem solution, and the partner asks questions if something is unclear or incorrect and gives hints if necessary. The partners periodically alternate roles [18, pp. 121–122].	S
Make up problems. Make up (or make up and solve) a problem suitable for a course assignment or exam. The problem should require the solver to exercise high-level thinking and problem-solving skills. This is an excellent exercise for helping students develop creative thinking skills [18, pp. 228–229].	A, S
Peer review. Individual students or student teams write reports on an assigned reading, video, screencast, or tutorial. Each student or team exchanges drafts with another student or team, provides feedback, and returns the draft and feedback to the author(s), who revise their reports and submit the revisions to be graded.	A, S
Pair programming. Students work in pairs to generate spreadsheets, computer simulations, or computer code, with one student serving as the pilot (working at the keyboard) and the other as the navigator (thinking strategically, checking for errors). The pair members periodically switch roles [19].	S
Simulations and labs. Individual students or teams use a computer simulation of a process or a remote-controlled or virtual laboratory or home test kit to design and conduct experiments. The students analyze and interpret the data and write and submit reports.	A
Team studying. The course instructor prepares examination study guides and students use the guides to test themselves and one another.	A
Generate a document. Student teams use document-sharing software or electronic whiteboards to produce text, diagrams, slides, spreadsheets, wikis, and almost anything else they are called on to generate in an in-class activity, assignment, project, or test.	A, S
Discussion board. Students post questions, responses to instructors' prompts, and responses to other posts (details given in a later section).	A
Cooperative learning. Student teams complete projects under conditions that establish positive interdependence of team members and individual team member accountability (details given in a later section).	A

communications. If you ask a question with an immediately obvious answer and send the students into breakout rooms to answer it, you are wasting class time, and at least some students will know it and resent it.

- *Before you send students into breakout rooms, give them clear instructions about what they are supposed to do.* If you don't, the groups will end up wasting a lot of time going off in the wrong direction, or calling for the instructor to visit their room and help, or leaving the room, asking for help, and then returning to the room. Consider putting instructions in a shared document that the students in all breakout rooms can access.
- *Keep groups together throughout class sessions.* Groups may take a long time to get activities started the first time they work together. The setups can take up a large portion of the session time if you change groups from one activity to the next, so don't do it. Changing groups between sessions is fine.
- *Keep the activities short and focused.* In F2F classes, 10 s – 3 min is a good guideline for most activities. In online classes where sending groups to breakout rooms and then recalling them can each take considerable time, 2–8 min should generally be enough. Before the first breakout session, let the students know that they may not have time to complete the assigned activity: the idea is for them to do as much as they can in the allotted time, and the full solution will emerge after the class reconvenes.
- *Don't just call for volunteers to report out after you terminate every activity.* The students will quickly realize that that's what you're going to do, after which many won't make a serious effort to do the requested work. On the other hand, if you randomly call on individual students or groups after at least some of the activities, the students' knowledge that they might be called on will motivate most of them to try to be ready with an answer.

Most quantitative STEM problems take longer than eight minutes to solve. If you want your class to work through a long problem, break it up into smaller chunks. For example, make the first breakout room activity getting the solution started ("See how far your group can get in ___ minutes.") End the activity at the designated time, recall the class, and call on students to report what they did until the correct start of the solution has been elicited. At that point, you may discuss the solution strategy ("Why did we start with *that* equation?"), quickly lecture through straightforward subsequent steps, and when you get to the next challenging part, send the students back to the breakout rooms to figure it out.

An essential condition for making actively engaged problem solving effective, whether in an F2F or an online class, is buried in that last sentence. If you break a substantial problem into chunks and send students into breakout rooms to work out each chunk, bring them back, process the chunk with the whole class, send them all back to their breakout room to work out the next chunk, and so on, it could take several class sessions to work through the complete solution – and all that for just one problem. The key is to use activities only for the difficult or tricky parts of the problem and quickly show the solutions of the straightforward parts to the whole class using slides or a document camera, whiteboard, or tablet computer. Alternatively, put the straightforward solutions in a handout all the students have, leaving gaps to be filled in with the solutions the students work out in the breakout rooms [18, pp. 81–84].

4. Online Discussion Boards

In F2F classes, in-class discussions can get students to think deeply about course content. Research supports the instructional value of whole-class discussions [20, 21], and much of the active learning literature supports the value of discussions in small groups [1, 22, 23]. Discussion boards, in which students asynchronously post responses to instructors' prompts and to other students' posts, provide similar benefits online in general [7, 20, 24] and specifically for STEM courses [25]. An additional benefit of discussion boards is that they engage students in writing about their discipline, an approach that may deepen their conceptual understanding as well as improving their writing skills [26].

This section examines the following questions:

1. *What is known about the benefits of discussion boards and how to structure them effectively?*
2. *Once I set up discussion boards, what should my role be in them and how active should I be?*
3. *Should I assess the quality of student posts? If so, how, and how can I do it without spending an unreasonable amount of time?*

4.1 What is Known about the Benefits of Discussion Boards and How to Structure Them Effectively?

Both users and researchers cite numerous benefits resulting from the judicious use of discussion boards (DBs), including engaging students with course material at a relatively deep level, promoting social presence, and paving the way for peer tutoring and team project work. Under certain conditions, DBs also help cultivate *teaching presence*, students' sense that their teacher is a real person who is actively involved in course planning and delivery and concerned about the students and their learning. Like social presence, teaching presence is an important factor in online students' satisfaction with their courses [4, 5, 27–30].

Not surprisingly, the use of DBs correlates with students' academic performance, satisfaction with courses and instructors, and development of high-level thinking and problem-solving skills, provided that the instructor's prompts and assessments specifically address those skills [31–35]. In addition to providing those benefits, DBs promote equity and inclusivity in online courses. Tanner [36] describes equity as giving all students the chance to verbally participate, have time to think, suggest their own ideas, and be welcomed into the classroom discussion. DBs can stimulate engagement of students who may for various reasons shy away from active participation in F2F class activities, including strong introverts, members of underrepresented groups, students who need more time to gather their thoughts than synchronous discussions allow, students uncomfortable with the language of the course instruction, and students with speech or hearing impediments or learning disabilities [37].

While most common learning management systems make it relatively simple to set up a discussion board, the challenge lies in setting it up in a way that encourages full student participation and deeply reflective comments (as opposed to superficial responses such as "I agree with Susan's comment" or "I don't understand anything.") DBs range in structure from basically none (the instructor sets the DB up, students post questions and answers if they feel so inclined, and the instructor plays little or no role in the discussions) to highly structured (instructors seed discussions with prompts and questions, set minimum requirements for students to post and respond, clarify points of confusion, move discussions to higher levels of thinking, help to resolve conflicts, and intervene when students' postings are inappropriate).

Research offers some clear messages on the effects of different discussion board structures:

- *DBs that require or at least incentivize student participation are more effective at engaging students than those that simply offer students a way to connect* [5, 31, 38–41].

Most published discussions of DBs agree that participation should count toward the final course grade by a small amount, either directly or through bonus points on exams [41, 42]. A study of two undergraduate accounting classes found that bonus points were effective at eliciting student participation early in the course. Once a learning community established itself in the class and the students became familiar with how the DB worked, the incentives did not make a noticeable difference in participation levels [43].

- *The number of new student postings to a DB (as opposed to simple comments on previous posts that do not introduce new material) correlates positively with students' course grades.*

In a study of an online engineering management course [35], the students regularly selected a topic, posted several paragraphs reflecting on it, and explained why it was important. The authors used correlation and multiple regression analysis to determine the extents to which eight variables contributed to the students' final grades in the course. Prior academic performance and number of new postings to the DB were the only variables examined that contributed significantly. The variables that failed to do so included age, gender, whether students resided on or off campus, major fields of study, number of posted messages read, and number of follow-up and reply postings. In both the correlation analysis and the regression, the two contributing variables were independent of each other, indicating that the results were not simply a matter of the stronger students participating most actively in the DB.

- *Instructors' DB prompts and questions should reflect their learning objectives.*

If the objectives include development of high-level thinking and problem-solving skills, the course learning objectives should involve those skills and the prompts and questions should require exercising them. Guidance on writing learning objectives that promote high-level learning and skill development is provided by Felder and Brent [18, Chs. 2, 9, 10]. If, for example, an objective of the course is for students to develop critical thinking skills [18, pp. 230–235] or creativity [18, pp. 222–230), prompts should require those kinds of thinking, and exemplars should be given as models of what the instructor is looking for [40].

Clark and Bartholomew [44] conducted a qualitative study in which they categorized instructors' comments on DB posts as cognitive (challenging, questioning, or probing for deeper thinking or elaboration), teaching (summarizing, sharing, or connecting ideas, providing resources), or social (encouragement and compliments, sharing personal experiences). They found that the instructors provided substantially more teaching and social comments than cognitive comments. When cognitive comments *were* provided, students perceived the teacher as encouraging in-depth thinking and responded accordingly.

- *Different types of questions elicit different levels of discussion.*

Kortemeyer [45] analyzed students' DB postings and accompanying chat comments in three introductory physics courses in which the instructors assigned problems that called for numerical calculations, variable estimations, and conceptual understanding. Single-response, multiple-choice and numerical problems led to significantly fewer conceptual discussions than problems that called explicitly for conceptual understanding, but even numerical problems stimulated rich conceptual discussions when the students were prompted to justify their responses or discuss the assumptions they made. Good prompts might involve ConcepTests (multiple-choice questions in which incorrect responses include common student misconceptions), explaining discrepant events (Why is there frost on the grass on a morning when the temperature never reaches freezing?), or coming up with examples of a concept or tool (Describe a familiar household control system using the concepts and vocabulary in the reading).

- *Open-ended prompts lead to higher-level discussions than single-answer prompts.*

A common difficulty in problem-solving DBs is that once someone suggests a solution, the discussion tends to stop, even when students are asked to provide multiple solutions or ideas for attacking the problem [46]. In one illustration of this phenomenon, Nandi et al. [34] conducted a qualitative analysis of student posts in two online computer science courses, with student tutors facilitating most of the discussion boards. In the first course, the questions were almost entirely formulaic and posting solutions often shut down further discussion, while in the other course many questions could not be answered with a simple response, and the students discussed the topics more freely and posted examples from their own experiences. Instructor-provided exemplars of good responses generally led to deeper discussion and more meaningful learning.

There are an unlimited number of possibilities for effective open-ended discussion board prompts. Here are several of them.

- Some of you complained that my explanation of the solution to Problem 11.3 was unclear. What might be a better way to explain it?
- We spent a great deal of time yesterday deriving an expression for y as a function of x (substitute real process variables for x and y). (a) Outline several ways to prove that the derived expression is correct (or to show that it isn't), and/or (b) Suggest some real-world applications of the expression, and/or (c) Suppose that the system is built and run, and the measured value of y does not agree with the predicted value. Suggest possible realistic explanations, considering the derivation, the operation of the process, and the measurement of y as potential sources of the discrepancy.
- A recent op-ed column concerning climate change is posted on the course website. Suggest arguments that either support or contest the columnist's opinion and/or respond to other students' posts on the issue. To get credit, your posting must offer evidence to support your argument and must follow the civility norms set out in the syllabus. Whether you agree or disagree with the columnist will make no difference.
- I'm thinking about replacing the third midterm exam in the course with a project. Good or bad idea? Explain your response.

DBs are usually set up as whole class discussions, but there is evidence to suggest that small group discussion boards provide unique benefits. For example, conducting discussions in groups of 4–5 in a graduate level class in assessment and data analysis led to a greater sense of social presence for students than was observed in a class that used only whole-group DBs [47]. Small-group DBs may also be used to facilitate team project work, as discussed in the upcoming section on cooperative learning.

4.2 Once I Set Up Discussion Boards, What Should My Role Be in Them and How Active Should I Be?

Many references note the importance of active instructor participation in DBs [e.g., 29, 31, 33]. The benefits cited include raising the number of student postings, promoting deeper thinking about discussion topics, and keeping discussions from wandering too far off topic. At the same time, instructors are cautioned to avoid over-involvement, which can cause students to become overly reliant on the instructors and decrease their own contributions [33, 42].

Scaffolding – providing a high level of support early in an enterprise and gradually withdrawing it – is an effective strategy for adjusting the levels of discourse and instructor involvement in discussion boards. Course instructors' prompts should initially be fairly frequent to create momentum and should focus on basic knowledge and personal reflections to help establish good instructor-student and student-student relationships. As the course proceeds, the prompts should move toward higher-level thinking and problem-solving skills, and the instructors should back off but continue to monitor the board and be ready to jump back in to start a new thread or to intervene when students reach an impasse [29, 33, 42].

Students' academic levels should also be a factor in decisions about how much support instructors should provide. Early in undergraduate curricula when most students have never experienced demands of the kinds effective DBs impose, a moderately high level of instructor involvement is appropriate. As the students advance, the level of instructor involvement should steadily decrease, and as the students approach graduation, more than minimal involvement could be counterproductive [33].

4.3 Should I Assess the Quality of Student Postings? If So, How, and How Can I Do It Without Spending an Unreasonable Amount of Time?

A study of 23 community college courses [5] showed that generally few students contributed to DBs, and when they did participate, their posts were minimal and low-level. In several of the courses, however, the instructors explicitly communicated what a high-quality post or response to another's post might look like, and students subsequently posted more frequently and thoughtfully.

That study illustrates a widely replicated finding that evaluating and providing feedback on postings effectively increases their average quality. Conducting a detailed content analysis of every post is impractical, however. A manageable way to assess contributions of individual students to a DB is to use a *grading rubric* – a form that lists the criteria to be used for grading a student product and assigns a range of ratings (such as a Likert scale of 1–5) or maximum point values to each criterion. Rubrics have been found to correlate with increased number and variety of student interactions in DBs [38]. Several publications present rubrics for discussion [48, 49], and many other examples can be found online with a search for "discussion board rubric."

Another rubric-based strategy for assessing the learning in DBs is to have students develop a participation portfolio. Nilson and Goodson [7] describe an implementation of this approach in which students are asked to select posts that illustrate their best work over a 2–4-week period, self-grade them using a rubric, and then submit the results to the instructor. The instructor then looks at the portfolios and accepts, raises, or lowers the grades the students gave themselves. This procedure makes assessment more manageable for the instructor by shifting responsibility to the students to select their best work and justify their self-grades, both a reflective and a metacognitive task.

In summary, discussion boards are popular in online classes for a reason. When carefully crafted, they can lead to deeper student reflection and levels of engagement with the course content, other students (social presence), and the instructor (teaching presence). Effective learning is more likely to occur when instructors accompany DBs with clear expectations and exemplars for constructing posts, ask questions and respond to posts, and create clear assessment tools and share them with the students. Table 2 summarizes key strategies for designing, implementing, and assessing students' contributions to discussion boards.

5. Cooperative Learning in Online Classes

Teamwork is a common feature of STEM classes. Well-structured team assignments have been shown to promote students' grades, intrinsic motivation to

Table 2. Recommendations for Using Discussion Boards

	Strategy
Planning	Formulate learning objectives you want to address in the DBs and write clear prompts to get at the learning you are looking for [5, 34, 45, 49].
	Provide structure appropriate to the level and experience of students (more guidelines and deadlines early in the curriculum, more autonomy for more mature students) [5, 34, 40–42, 49].
	Early in the course, explain what the DBs will be used for and why they are important [34].
	Develop a rubric to establish clear expectations for posts and have students use it to rate sample postings and discuss the ratings before you use it to rate their posts [18, pp. 176–182]; [25, 38, 48–49].
Instructor's role once the DB has been created	Encourage students to think deeply about the content by showing some exemplars of what you expect from them as you introduce new higher-level thinking strategies [29, 34, 50].
	Encourage continued participation throughout the semester by asking questions and sharing experiences and applications. Don't overdo your commenting, however: provide more input early in the semester and gradually decrease it [25, 31–32, 34, 44].
Assessment of learning	Use a rubric to assess the quality of student posts so that you are looking at quality as well as quantity of new posts and responses [38, 49].
	Have students develop a portfolio of their best posts, self-assess the portfolio using a rubric, and submit the portfolio and the completed rubric to the instructor for final assessment [7].
	Assign points or a percentage of the final grade for number and quality of new postings and responses [41–43].

learn, development of high-level thinking and problem-solving skills, self-efficacy, positive relationships with peers, and persistence through graduation, and reduced levels of anxiety and stress [51]; [52, Ch. 10]; [53–60]. Meta-analyses of studies specifically of computer-supported teamwork in STEM courses confirm the positive impact of that teaching approach on students' learning, motivation, self-efficacy, and attitude toward their curricula [61–62].

Simply putting students in teams does not guarantee that the students will develop good team skills, however, as anyone who has been involved with team project work as either a student or an instructor can attest. Research has repeatedly shown that the quality of interactions between students and instructors and among students are both strong determinants of a program's success, and intra-group emotional support is the core element from which those interactions are configured [61]. The literature also suggests that such support does not naturally occur when students are simply put into groups for assignments and projects: instructor-provided organizational and emotional support along with the usual educational support early in the group experience are required to develop it.

Two terms – *collaborative learning* and *cooperative learning* – are commonly used to label approaches to projects in which students work in groups to achieve a specified goal. As they are generally defined, collaborative learning involves minimal instructor intervention, while in cooperative learning (CL) the instructor chooses between instructor-formed and student self-selected teams, specifies team-formation criteria, structures the course to promote students' development of both technical and teamwork skills, and puts policies in place for dealing with the problems that inevitably arise with both student and workplace teams. Davidson [63] surveys widely-used models for making and implementing those choices [63]. Of those two approaches to teamwork, cooperative learning has been much more widely used in STEM education, owing in part to the emphasis on high-performance teamwork skills and product quality that it shares with approaches to team project work in business, industry, and scientific research.

While most of the cooperative learning literature relates to F2F classes, the approach has been successfully applied to online instruction. A fundamental premise of CL is that real-time interactions among team members – reporting on their individual work, checking and discussing one another's work, resolving differences of opinion, and providing mutual encouragement and support – lead to a significant percentage of the learning that occurs in team assignments and projects. Noting that the customary definition of asynchronous online instruction does not involve synchronous meetings of students, Davidson [63] proposes defining asynchronous cooperative learning as instruction in which entire classes do not meet synchronously but project teams do.

A CL model formulated by Johnson, Johnson and Smith [54, 64] has been used extensively in STEM education and will be the only one considered in the remainder of this section. The model stipulates that group projects must incorporate five tenets: (1) positive interdependence, (2) individual accountability, (3) promotive real-time student-student interactions, (4) appropriate use of collaborative skills and (5) regular self-assessment of team functioning. Table 3 describes each tenet in more detail. Felder and Brent [18, Ch. 11]; [65] outline how to implement the model in STEM courses, offering suggestions relating to team formation and norming, structures for assignments and projects, establishing the five CL tenets, and dealing with dysfunctional teams. The suggestions in those references are oriented toward F2F instruction, but since some interactions among teammates in both F2F and online classes take place in

Table 3. The Five Tenets of Cooperative Learning

Tenet	Description
Positive interdependence	Team members must rely on one another to complete assignments. If any team members fail to do their part, everyone suffers consequences.
Individual accountability	All students in a group are held accountable for doing their share of the work and for mastering all the material to be learned, not just the parts for which they had primary responsibility.
Promotive real-time student interactions	Although some of the team's work may be done by individual team members, some must be done interactively with team members providing one another with feedback, modeling appropriate behaviors, and teaching and encouraging one another.
Appropriate use of collaborative skills	Students develop and practice trust-building, leadership, decision-making, communication, and conflict management skills.
Regular self-assessment of team functioning	Teams set goals, periodically assess what they are doing well, and identify changes they will make to function more effectively in the future.

synchronous team meetings, there are fewer differences between F2F and online CL than many instructors imagine.

In the remainder of this section, we will address the following questions:

1. *What do we know about the effectiveness of CL in online classes?*
2. *What teaching strategies promote each of the defining tenets of CL in online classes?*

5.1 What Do We Know about the Effectiveness of Cooperative Learning in Online Classes?

Hundreds of F2F studies attest to the effectiveness of CL at promoting learning outcomes including improved academic achievement, development of teamwork skills, retention in academic programs, perceptions of social support, and self-efficacy [53, 54, 56, 66]. Reviews of the literature on online instruction show less direct empirical support specifically for CL in online classes and more general support based on the presumption that the benefits of CL in F2F environments should carry over to online instruction [3, 39, 67–74].

Direct studies of online cooperative learning report mixed but generally positive results. Different authors have found that CL improved academic achievement in an online chemistry course [75] and worked equally well in online, hybrid and F2F environments [76], and online CL improved student motivation and attitudes [67, 72, 77–79] and skill development [80], while other studies report uncertain or no impact of CL on some specific measures of student learning [67, 68, 72, 80] and attitudinal outcomes [68, 81]. Several studies found that some strategies that effectively promote positive interdependence in F2F classes were less effective online [82–85].

Mixed results from studies of instructional methods are not uncommon. The effectiveness of any instructional technique depends on many variables, not least of which is how well the technique is implemented. The volume of research attesting to the positive impacts of CL on learning in F2F classes makes conclusions about its effectiveness in that environment unassailable. Online cooperative learning is newer and less heavily researched, however, and optimal strategies for its implementation are less well developed, which is one of the motivations for the current analysis.

5.2 What Teaching Strategies Promote Each of the Tenets of CL in Online Classes?

The cooperative learning literature contains many suggestions for promoting the five tenets of CL, some of them supported by research and others simply based on logic. The next several paragraphs and Table 4 outline strategies for establishing the five tenets online, with indications in the table of which strategies have direct research support for their use in online environments.

5.2.1 Positive Interdependence

One approach to promoting positive interdependence is to give assignments that are too challenging to be completed by most individual students in the allotted time. Instructors should not increase an assignment's level of challenge by simply making it longer, however, which can encourage students to divide the work among the team members without each of them understanding what their teammates did. The added challenge should instead come from requiring more high-level analytical, creative, and critical thinking [18, Ch. 9–10], incorporating training in those skills into the course instruction.

Another common strategy for establishing positive interdependence is to assign specific roles to team members. Several studies showed that assigning students to roles in online courses led to higher end-of-semester project grades than were earned by students in a control group without assigned roles [82, 86, 87]. There are two categories of roles – expert and management. Expert roles are assigned in a popular technique called jigsaw [88], in which different team members get individual training in different bodies of knowledge and skills needed to successfully complete the team project (e.g., library research, mathematical and statistical analysis, and computer simulation). The team relies on each of its members to bring their expertise to bear on the project work and to transmit their specialized knowledge to their teammates, who are held accountable for it if individual accountability (the second CL tenet) is maintained.

Management roles serve to help ensure that the team operates smoothly and effectively. A common set of management roles is coordinator (oversees project and time management), recorder (takes primary responsibility for assembling the final project report), checker (double-checks all calculations and everything else in the final report), and process monitor (makes sure all team members can explain everything in the final report). A good practice is to periodically rotate management roles among team members so that all students receive some training in the procedures and skills associated with each role.

Other strategies for establishing positive interdependence online are outlined in Table 4.

5.2.2 Individual Accountability

Peer assessment of individual contributions to team assignments promotes individual accountability in online courses [89]. A variety of online project management tools such as CATME [90, 91) and ePearl [92] facilitate such assessments. CATME, a suite of cooperative learning tools that includes a well-validated rubric for peer assessment of teamwork, has been used extensively in online engineering courses [93, 94].

In addition to promoting positive interdependence, assigning students to specific roles promotes individual accountability, especially if individual team members are held responsible by peer assessment for deficiencies in fulfilling their roles. In one study [95], assigning roles enhanced individual achievement as measured by learning gains in targeted skills even more than strategies designed to promote positive interdependence. Another study [41] used a jigsaw format to structure discussion forums in online computer science courses, giving student teams training in different topics and then having them share their knowledge with the rest of the class. These students' attitudes about the forums' usefulness were more positive than attitudes of students in classes that did not use this structure.

Several other techniques for promoting individual accountability that can easily be adapted to online environments are listed in Table 4.

5.2.3 Promotive Real-Time Student Interactions

This tenet of CL was originally called "face-to-face promotive interaction" and required that team members work together constructively at least occasionally, rather than simply dividing the work among themselves and binding the results together at the end. Examples of promotive interaction include team members sitting together at a real or

Table 4. Strategies for Incorporating the five Tenets of CL in Online Courses

Tenet	Supportive Course or Assignment Structure
	Assignments too challenging for individual students to complete in the time allotted [99].
Positive interdependence	Management role assignments (e.g., project coordinator, recorder, checker, and process monitor)* [18, p. 257]; [82, 86, 100].
	Jigsaw (expert role assignments)* [87].
	Structured team laboratory reports using Wikis* [101].
	Assigning one to three bonus points on exams when the average grade of the team members exceeds a specified value (e.g., 80) [18, p. 258].
Individual accountability	Scripted role assignments with explicit assessment of each role* [95].
	Discussion forums that incorporate a jigsaw format* [41].
	Team/project management software tools that use peer assessments to promote individual accountability [89–90, 92–94, 102, 103]. For example, CATME Smarter Teamwork (n.d.) is a widely used software package for team project management and evaluation that includes a validated peer assessment tool.
	Individual tests that assess team members' achievement of team project learning objectives [65, 104–105].
	Mechanisms to penalize noncontributing team members, such as leaving their names off submitted assignments or firing them from the team, the latter after first issuing a warning and seeing no change in behaviour [18, pp. 260-261]; [104].
Promotive real-time student interactions	Student training in group processing* [86].
	Discussion forums in which student teams are required to provide feedback on other students' work* [41].
	Prompting students to read other students' posts on discussion boards or tracked changes on shared documents and to provide feedback* [87].
	Using e-Rubrics to facilitate formative peer assessment of technical work in team projects* [106]
	Elaborated explanations [107].
	Team/project management software tools (e.g., CATME) that provide formative peer feedback on student performance [102, 103].
	Regular online team meetings for assessing team functioning and planning changes to improve it [18, p. 261]
Appropriate use of collaborative skills	Student training in group processing* [86].
	Holding team members responsible for resolving their own conflicts but providing guidance on dealing with dysfunctional team members using crisis clinics and active listening exercises* [18, pp. 264–268].
	Team contracts: Soon after teams are formed, the members formulate team goals and expectations and sign to indicate their agreement* [18, p.255]; [97, 108, 109].
	Team/project management software tools (e.g., CATME) that provide targeted feedback to individuals on how often they use recommended skills [90, 102, 103].
Regular self-assessment of team functioning	Team reflection exercises – regular sessions in which team members assess how well they are functioning and how they plan to improve* [18, p. 161]; [86].
	Team/project management software tools that allow assessment of team functioning [90,102–103]
	E-portfolios or e-journals that address team functioning [98].

* Supported by research on online classes.

virtual table providing explanations to one another and critiquing and correcting one another's efforts.

Interpersonal problems common in team-based learning can be exacerbated online; for example, the absence of nonverbal cues in text-based communication can promote misunderstandings, and asynchronous online discussion can fail to resolve the resulting conflicts in a timely manner [82, 96]. The synchronous promotive interactions that constitute the third tenet of CL are therefore particularly important in online courses. Video conferencing tools that convey facial expressions, tone of voice, and body language can and should be used to facilitate such interactions.

Nam and Zellner (86) examined the impact on team performance of online group processing, which they defined to include the last three tenets of CL (promotive interaction, appropriate use of collaborative skills, and regular self-assessment of team functioning). They trained students using structured assignments that promoted peer encouragement, giving and receiving feedback, and self-evaluating, and saw consequent gains in student achievement. Positive student outcomes were also seen in other studies when team members provided constructive feedback of one another's work on discussion boards [41, 87]. As a rule, instructors assigning team projects should familiarize themselves with conflict resolution strategies such as active listening, so that when dysfunctional teams encounter seemingly unresolvable problems the instructors can undertake interventions [18, pp. 264–266].

5.2.4 Appropriate Use of Collaborative Skills

All skills are acquired through instruction, practice, and feedback. Instructors of online courses promote practice in collaborative skills by using team assignments, and CATME and similar team-management tools in online courses can provide students with peer feedback on their collaborative skills. Explicit instruction in collaborative skills was shown in two studies to correlate with student achievement and satisfaction in online courses [86, 97].

5.2.5 Regular Self-Assessment of Team Functioning

In one study, incorporation of reflection exercises into online team assignments produced higher academic achievement [86]. Other strategies for promoting this tenet that have not been subjected to formal research studies in online classes include:

- Having teams regularly submit self-assessments of how well they are meeting their agreed-upon norms and outlining steps they plan to take to improve their performance [18, p. 161].
- Requiring teams to log their assessments in e-portfolios or e-journals [98].
- Using the CATME Smarter Teamwork suite of tools [90].

6. General Recommendations

Many reviews of the effectiveness of active online engagement strategies are meta-analyses, in which the authors round up all the studies they can find pertaining to a particular strategy, convert their assessment findings to a common basis (e.g., the effect sizes of comparisons of students' test grades when the strategy was and was not used), and aggregate results to reach a conclusion. A common attribute of those meta-analyses is substantial variability between individual studies, probably resulting in large measure from differences in how well the engagement strategies studied were implemented. Following are brief recommendations of teaching methods that consistently correlate positively with students' academic performance, along with citations of references that provide more details on their implementation. Using some of the recommended methods should increase the effectiveness of online courses, regardless of which active student engagement strategies the instructors adopt.

6.1 Make Your Expectations Clear throughout the Course

A common student complaint about online courses is confusion about the instructor's expectations. To be sure, confusion also occurs in F2F courses, but it is relatively easy for F2F students to get clarification from the instructor or neighboring classmates, harder for most online students, and even harder for online students who have limited access to or discomfort with technology.

Expectations of students fall into three categories: (1) the knowledge and skills the students are expected to acquire, (2) exactly what the students are expected to do on class activities, assignments, and tests, and (3) policies regarding attendance, submission of assignments (format, lateness), participation in discussions and class activities, cheating on assignments and tests (what constitutes it and what are its consequences), and criteria that will be used to determine course grades. The following strategies for clarifying expectations in these categories have all been found effective:

- *Write observable learning objectives and use them as a basis for aligning course syllabi, lectures, synchronous and asynchronous class activities, assignments, and tests. Share them with the stu-*

dents as study guides for midterm and final exams [18, Ch. 2]; [110].

- *Provide extensive formative assessment, which lets both you and the students know whether and how well they are progressing toward meeting your learning objectives* [18, pp. 94–95]; [52, 111]. Examples of formative assessment methods include monitoring students' questions in class and during office hours and their performance on in-class activities, out-of-class assignments, and low-stakes quizzes, and conducting surveys such as minute papers [18, p. 62] and mid-term evaluations [18, pp. 102–103] in which the students identify points of confusion.
- *Use rubrics to evaluate student products that require some judgment on the part of the grader.* Tests of factual knowledge and low-level quantitative problem solving are straightforward to grade, and students generally are not confused by the grades they receive on such assessments, especially if they are shown scoring keys. On the other hand, students are frequently confused by their grades on solutions of complex problems that can be approached in different ways, assignments that require critical or creative thinking, and project reports that have multiple assessment criteria (e.g., approach taken, completeness of background, data analysis, correctness of results, and quality of graphics and writing.)

In the sections on discussion boards and cooperative learning we introduced *rubrics* – grading tools that list the criteria to be used to evaluate student products and assign weights to each criterion. A well-designed rubric can dramatically increase assessment reliability while reducing grading time and the need for lengthy repetitive explanations of point deductions, and it also provides an excellent training device for clarifying the instructor's expectations and alerting students to common reasons for deductions [18, pp.176–182]; [112]. Rubrics for evaluating most common student products and skills including design project and lab reports and critical and creative thinking can be found by entering "Rubric [*product or skill label*]" into an internet search engine.

6.2 Take Steps to Establish Teaching Presence

An important element of student satisfaction with online instruction is teaching presence, students' sense that their online instructors are real people who are personally involved in their instruction [29]. A high sense of teaching presence correlates with motivation to learn, academic performance, persistence to course completion, and intention to enroll in future online courses [5, 8, 28, 29, 113, 114].

Measures that establish and maintain teaching presence have been suggested by several authors [4, 5, 13, 27–30, 115]:

- Before the first day of class, send a welcome message to all enrolled students describing the course, its importance in the curriculum and the course discipline, and the types of scientific, industrial, and societal problems the course material may help to solve. In addition, post a short video introducing yourself, perhaps mentioning your background, research, personal interests, and why you are enthusiastic about teaching the course.
- In the first week of class, require all students to send you a short message containing some facts about themselves and their interests and statements about what they hope to get out of the course. If the class size allows it, schedule a short get-acquainted video chat with each student in the first two weeks.
- Communicate course structures and policies explicitly and clearly, including course learning objectives, information about assignments and tests (including policies related to academic integrity), and how course grades will be determined.
- Announce how students can contact you with questions (e.g., with postings on the class computer interface or discussion boards or with text or email messages).
- Deliver weekly announcements to the class in short videos.
- When individual students raise questions or identify points of confusion by directly communicating with you, respond to them promptly. When you identify common points of confusion from direct communications, quizzes, assignments, minute papers, or exams, address clarifications to the entire class by email or postings to discussion boards. In the latter case, first give other students opportunities to respond.
- Hold virtual office hours during which you are available to receive students' questions and requests.
- Periodically acknowledge your awareness that students have demands on their time other than your class and emphasize your availability to help.
- Contact students who are struggling in the course, try to determine what the problem is, and offer suggestions for what they might do to remedy it.
- Even if the course is primarily asynchronous, try to arrange several synchronous sessions, such as review sessions before exams.

6.3 Take a Gradual Approach to Course Development

This article suggests many strategies for actively engaging online students with one another, and their number would be enormous if all their variations were separately listed. The idea is not to adopt every possible strategy in your next online course, which would overwhelm both you and your students with unfamiliar challenges. Rather, select one or two strategies that look appropriate for your course and teaching style, and try them often enough for both you and the students to get accustomed to them. If a strategy seems to be working well, keep using it; if it doesn't, have someone knowledgeable check how you are implementing it, try modifications they may suggest, and if the strategy still doesn't work well, stop using it. Next time you teach the course, try another one or two strategies. It should not take more than two or three course offerings to approach a level and quality of student engagement that meet your expectations.

7. Summary and Suggestions for Future Research

The positive impacts of well designed and implemented student collaborations on students' motivation to learn, academic performance, persistence to course completion, and satisfaction with their courses and instructors have been clearly established by research. A benefit of collaboration specific to online instruction is its critical role in establishing social presence, students' sense that their classmates are real people who are potential sources of encouragement and support. The absence of social presence leads to students feeling isolated and demotivated, while its presence correlates strongly with the outcomes just stated.

Most collaborative activities conducted in live F2F class sessions and all out-of-class F2F activities can be done in online courses. Tasks assigned to student groups should be challenging enough to justify the additional time required by online group activities – giving students a trivial task like answering a simple question and sending them into groups to find the answer is a clear waste of their time and is likely to provoke resentment.

Discussion boards are powerful devices for getting students actively engaged in asynchronous online instruction. When suitably designed and monitored by the instructor, they can facilitate reflection and analysis of course content at depths rarely attained in F2F classrooms, help establish both social and teaching presence, and promote equity and inclusiveness. Instructors should structure guidelines and prompts to promote the desired student participation levels, behaviors, and depths of thinking, being sure to provide clear assessment criteria and exemplars of good work. Instructors should also take care to strike a balance between insufficient personal involvement, which can lead to low student participation and superficial discussions, and excessive involvement, which can contribute to instructor burnout and make students overly reliant on their instructors to provide all the answers.

The reasons for instructors to use team project assignments – the desirability of equipping students with teamwork skills and the documented benefits of student-student interactions – are the same for both online and F2F instruction. Cooperative learning provides an effective structure for team assignments that includes *positive interdependence* (team members must rely one another), *individual accountability* (all team members are held accountable for the entire project and not just the parts they focused on individually), *promotive real-time student interactions* (student teams sometimes meet and work synchronously), *appropriate use of collaborative skills* (e.g., leadership, communication, and time, project, and conflict management), and *regular self-assessment of team functioning*. Strategies that promote the tenets in online classes include scripted role assignments (positive interdependence, individual accountability, promotive interactions), team contracts and student training in group processing (appropriate use of collaborative skills), and periodic team reflection exercises (regular self-assessment of team functioning). Instructors should be aware that asynchronous online environments can exacerbate normal challenges to communication and teamwork, increasing the need for regular self-assessment to catch problems early. Synchronous online team meetings help address those challenges, especially if videoconferencing software is used that conveys facial expressions, tone of voice, and body language.

To maximize the effectiveness of online instruction regardless of which student engagement strategies are employed, (a) make your expectations as clear as possible by monitoring student questions and responses, using a variety of formative assessment techniques, and using grading rubrics for assignments and projects that require high-level thinking and problem-solving skills; and (b) establish and maintain teaching presence by communicating regularly with individual students and the entire class. In addition, don't undertake too many unfamiliar teaching strategies at one time but rather take a more gradual approach to course development: adopt a small number of new techniques, use them enough for both instructors and students to become accustomed to them, decide whether to continue or drop them, and then try one or two more new techniques. If you adopt that approach, neither you nor the students are ever pushed too far out of your comfort zones, and the courses steadily improve.

Our review of the literature suggests several good candidates for additional research on student collaborations in STEM courses:

- Studies of collaborative engagement strategies in online STEM courses that use validated instruments to measure student learning and attitude outcomes.
- *Second-generation research* [1] that asks which features of online group work correlate with specific student outcomes, for which students and under what conditions the correlations are applicable, and which pedagogical and technological attributes of those strategies contribute most to their effectiveness.
- Determination of differences in impacts of structured group work on learning and attitude outcomes between different student populations (men and women, majority students and members of underrepresented groups, different learning style preferences, different levels of outside professional and personal commitments, different levels of prior experience with structured group work, etc.)
- Qualitative research on ways different students respond to specific engagement strategies.
- Examination of whether findings for the impact of collaboration in face-to-face courses, such as its role in closing the achievement gap between majority students and students in underrepresented groups, are also found in synchronous and asynchronous online courses.
- Studies of the impacts of discussion boards in online STEM courses.
  - Comparisons of achievement of high-level thinking skills and conceptual understanding in STEM courses taught with and without DBs.
  - Comparisons of learning outcomes for different types of prompts and levels of instructor posting.
  - Case studies of instructors who use DBs, including the types of prompts used and types of responses in different STEM disciplines, to provide more relevant examples for instructors just starting to use the technique.
- Studies of the impacts of cooperative learning in online STEM courses.
  - Comparison of learning outcomes between online courses that incorporate one or more of the CL tenets with outcomes from online courses that use student groups without establishing the tenets.
  - Comparison of learning outcomes between online courses adopting the different strategies listed in Table 4 for incorporating specific CL tenets, testing the relative effectiveness of each strategy.

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