

Using CONSIDER, a Novel Approach to Conflict-Driven Collaborative-Learning, in a Programming Languages Classroom

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ABSTRACT

Piaget’s classic work on how children learn showed that when learners engage in critical discussions with peers who have ideas that conflict with their own, that contributes effectively to their developing deep understanding of the concepts involved. Building on this foundation, we have developed a novel and powerful approach to collaborative learning that exploits the power of online technologies to enable CS – more generally, STEM– students to develop thorough understanding of technical topics through collaborative learning. Our approach, as we show, has a number of important advantages over most approaches to face-to-face collaborative learning. We have implemented a prototype web app, CONSIDER, based on our approach and used it in a Programming Languages course. It was very well received, with most of the students indicating, in a post-discussion survey, that the approach helped improve their perceived understanding of the topic discussed (from an average of 3.5 before the use of the tool to 4.6 after on a 5.0 scale). We present a summary of the survey results, along with the theoretical underpinnings of the approach and some details of the prototype implementation; we also present our design for the next set of experiments with the CONSIDER tool.

CCS Concepts

•Applied computing → Collaborative learning;

Keywords

Cognitive Conflict, Collaborative Learning

1. INTRODUCTION

The type of conflicts of opinions and the ensuing argumentation seen in the broader public sphere would make it difficult for one to imagine that any type of conflict could ever be collaborative, let alone a driver of effective learning. But researchers in learning sciences have been study-

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ing what Andriessen [1] calls *collaborative argumentation*, which “can help students learn to think critically and independently about important issues and contested values”. Indeed, Piaget [13], as part of his classic work on how children learn, shows that cognitive conflict arising from differences between different learners’ understanding of important concepts, and the exploration and possible resolution of these differences by having the learners engage in critical discussion with each other, can be a powerful force in driving children’s learning and in helping them develop deep understanding. In this paper, we report on a novel and powerful approach to collaborative learning that builds on the foundation of cognitive conflict and exploits the power of online technologies to enable graduate and undergraduate Computer Science students and, more generally, STEM students, to develop their understanding of technical topics through collaborative learning driven by cognitive conflict.

There are some challenges in developing such an approach. First, there are important differences between the children that Piaget’s work addressed and college students, especially with respect to their willingness to participate in discussions with their peers. While most young children, after perhaps an initial period of reluctance, willingly engage in such discussions, many college students, particularly in CS and, more generally, STEM courses, tend not to. This is especially the case with many female students and students from underrepresented groups [7]. Second, in many college courses, including in CS, large class sizes (40+) and short meeting times (~55 minutes) are the norm. This makes it difficult to arrange students in groups of 3–4 each and have each group engage in deep discussions in class without each group disrupting other groups’ discussions. Our approach not only addresses both these issues, it also has a number of other important advantages over in-person collaborative learning.

The paper is organized as follows. In Sec. 2, we review background theories and some related work. We describe our approach in Sec. 3 and also briefly describe the prototype implementation of a web app based on the approach. We used it in a senior/graduate level programming languages course in Spring-2015, where a course assignment, in the form of a discussion on how Lisp, being a functional language, differs from imperative languages like C++ and Java, was conducted using our app. After the completion of this activity, students were asked to complete a survey about their experiences in using the tool. In Sec. 4, we present an analysis of the survey results which suggest a very positive effect of

the approach on students' learning, and highlights the importance of various features of our approach. We conclude in Sec. 5 with a brief summary and plans for future work.

2. BACKGROUND

Our approach builds on two key notions that have been used successfully in various branches of learning sciences over the past few decades: Cognitive Conflict Driven Learning and Computer-Supported Collaborative Learning.

Cognitive Conflict Driven Learning.

Piaget's original ideas, including those on cognitive conflict triggering learning in children were further elaborated and expanded by various learning scientists and applied to K–12 as well as college education. For instance, Doise and Mugny [5] conducted various studies about how cognitive conflict impacts learning. Their work showed that the other learner(s) who held the conflicting views did not need to be *physically present*, as long as the learners in question saw the conflicting views as being those of *peers*. While triggering cognitive conflict *is possible* even without engaging with peers, e.g., via refutation text instead [17], combining it with peer-interaction has major advantages. First, interaction with peers encourages the student to verbalize the cognitive conflict. Such verbalization of the conflict, and not the presence of conflict alone, is important for improving learning [8]. Second, the learner is forced to consider the alternative explanations offered by the peers and evaluate them on equal terms given that the cognitive conflict facing the learner is caused by the difference between the learner's own position and a *peer's* explanation rather than one offered by an authority figure such as a teacher or a text. In the latter case, a learner may simply accept the alternative explanation without critical evaluation. By contrast, when the (cognitive) disagreement is with the peers, the learner is forced to evaluate the alternatives critically since, for all (s)he knows, it may be the *learner's* position that is correct rather than the peer's.

One recent classroom-approach in which cognitive conflict plays a central role is *peer-instruction* (PI) [12]. In PI, each student individually answers a conceptual multiple choice question, submitting the answer via a *clicker*; then the students turn to their neighbors and, in groups of 3 or 4, discuss the question; after a few minutes of discussion, each student again answers the same question. During the discussion time, the instructor walks around the room, observing the discussions but not participating in them. Mazur [12] reports that the percentage of students who, following discussion with their peers, change their answer from a wrong choice to the correct one far exceeds the percentage who change from the correct choice to a wrong one, demonstrating the power of collaborative learning driven by cognitive conflict. But there are a number of limitations with PI, mostly related to the fact that it is a classroom technique: (a) Since the multiple-choice question is about the topic being discussed in the lecture, students may not have had enough time to think about it deeply; (b) The groups are formed primarily based on which students happen to be seated next to which other students, rather than on the basis of ensuring cognitive conflict in each group; (c) Some students may dominate their groups irrespective of whether they have the right answers or not; (d) The amount of time spent in the discussion is limited; hence, students who need

time to formulate their arguments may not contribute effectively. As we will see in the next section, our approach addresses all of these limitations.

Computer-Supported Collaborative Learning.

Computer-Supported Collaborative Learning (CSCL) is a branch of the learning sciences that is "concerned with studying how people can learn together with the help of computers" [16].

CSILE (now KnowledgeForum) was one of the earliest CSCL systems [15]. A group of students using CSILE focuses on a specified relatively broad problem and begin to build a database of information about the topic. There is opportunity for reflection and peer review of each others' contributions by students. More recently, some authors used wikis to allow users to add, modify, or delete content using a standard browser, to create a site that thoroughly explores a topic. But, unfortunately, many of those studies have not produced as good results as expected (see, e.g., [3, 9, 10]). An important reason could be the fact that there is little or no structure to the activities in these uses of wikis. On the other hand, in our approach, the activities are designed to trigger cognitive conflict leading to students engaging in effective collaborative learning.

Some researchers have suggested that technology, which is indeed the backbone of CSCL, should be exploited to realize some unique possibilities: (a) The fact that CSCL environments can record the interactions in detail allows researchers to *zoom in* and see what exactly is going on during the collaborative interactions [4], making it a richer design environment for the researcher; (b) Computational media, being configurable and adaptive, can make *new* interactions possible, instead of just replicating the face-to-face ones [16]. Our approach records the interactions in details, as well as creates new interactions via anonymous and asynchronous comments in a structured way. Indeed, it is these new types of interactions that are at the heart of the power of the approach.

We would like to mention that CSCL emerges from a wider research area—Computer Supported Cooperative Work (CSCW) [18]. Some recent works that are on the cusp of CSCW/L include the work by Greiffenhagen [6] which discusses how learning can change due to introduction of technology, using a study where students learn about *Macbeth* by producing their own storyboards in a CSCW software, and Maldonado and colleagues' study that analyzes the effects of deploying and visualizing the teacher's script for small group idea generation, using interactive tabletops, etc. [11].

3. APPROACH AND PROTOTYPE

In our approach, all students in the class are presented (via an on-line system, as described below) a multiple choice question about a concept recently discussed in class. They have to individually select one of the options and justify their choice. Based on these answers, the students are organized into groups of 3–4 each, such that each group has students who had conflicting answers to the initial question. Students in each group are assigned anonymous identifiers S1, S2, etc., which stick with them till the end of the discussion phase. After this group formation phase, all groups are given a common, more detailed assignment; the underlying topic of this assignment is the same as that of the initial question. Discussion takes place in a series of *rounds*, each lasting 24

hours, in which each student in a group makes exactly one *post*. Round R_0 may be thought of as the one corresponding to the initial question and the explanation provided by each student for that question serves, in a sense, as the starting point for the first round. In each round R_k after the zeroth one, in each group G , a student, say $S1$, can access the posts of each of her peers –say $S2$, $S3$ and $S4$ – from the previous round R_{k-1} , and indicate whether she agrees with, disagrees with or is neutral towards each of those posts. She does so by clicking a green, red or blue button, respectively, next to each post, and justifying those button clicks in a text box provided. She has to do this for every peer’s post, *including her own*. This is important because $S1$ may find the post (from the previous round) of one or more of her peers so compelling that she changes her mind and no longer agrees with what she herself said in the previous round! This is the *essence* of collaborative learning driven by cognitive conflict. $S1$ may edit her post for this round at any time during the 24-hour period. At the end of this period, the round finishes, a new one begins, and all students in G will be able to see the posts that everyone in G made during the just-ended round. The discussion will end (typically) after three rounds (not including R_0) at which point each student in G will be required to, *individually*, submit a summary of the discussion in G and her own final answer to a question related to the discussion. The student’s grade for the assignment will depend *only* on this final submission which means that she has to be fully engaged in the group discussion to be successful; *and* there is no penalty for changing her mind about her original answer to the initial question or the question that the group discussed.

We call the approach CONSIDER, short for CONflicting Student Ideas to be Discussed, Evaluated, and Resolved. While the basic idea of cognitive conflict driving collaborative learning is based on earlier work, our approach, by careful use of the power of online systems, not only addresses the challenges to students learning listed earlier, but also offers a number of other important advantages. Anonymous posting lets students participate freely, mitigating any prejudices or biases some students may have about others. Asynchronous discussions allow time for students to carefully study their peers’ arguments and formulate their own. Neither of these features is possible, or at least practical, without the use of technology.

We have implemented the approach as a scalable, platform-independent web app, using Google App Engine and Python, making it ubiquitous, accessible from any net-connected device of choice of the students.

4. SURVEY DATA ANALYSIS

The CONSIDER tool was used in a theory of programming languages course in a large public university in the mid-western United States. The main goal of this course, like similar courses in other universities, is to study formal ways of defining syntax and semantics of programming languages. The main topics are attribute grammars; operational, axiomatic, and denotational semantics of languages. In Spring-2015, one of the assignments of this course was conducted as a CONSIDER discussion. The assignment was about how Lisp, being a *functional* language, differs from *imperative* languages, and how can the constructs of imperative languages, like an assignment statement, be implemented in a Lisp interpreter. Students in the course have typically

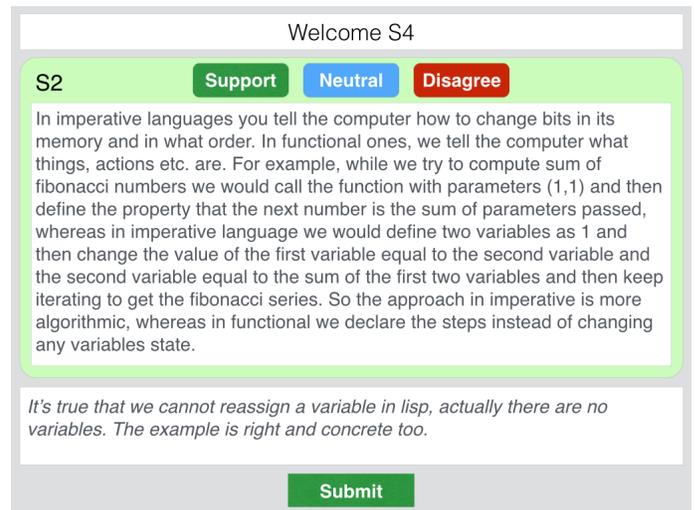


Figure 1: CONSIDER Discussion

not previously encountered functional languages, hence this can be a challenging topic for many of them. 39 of the 40 students used the tool; one student missed the deadline for answering the first ‘group formation’ question, and hence could not be included (he was given an equivalent assignment offline). The students were divided into nine groups of 4 each, with the tenth group having 3 students. The following question was used for forming groups of students with conflicting ideas:

Lisp is a *functional* programming language, not an *imperative* language. What this means for a Lisp user is (pick the one choice that you most agree with):

1. It doesn’t really mean anything since Lisp is as powerful as any other language. It is just a criticism used by people who don’t like Lisp.
2. It means that there are no assignment statements in Lisp. So algorithms that use assignments (which is pretty much *all* algorithms) cannot be implemented in Lisp; instead, you have to come up with completely different alternatives which is often not possible.
3. It is true that there are no assignment statements in Lisp. What that means is that we should use the other features of Lisp such as function parameters, defining new functions, etc. to get the same effect as having assignment statements.
4. It is not just assignment statements that are missing. It is everything else: sequential composition, if-then-else, loops, you name it! What a bogus language!
5. We talked about it in class but I have no idea what it means!

The discussion that followed was about whether it was possible to implement a construct that is equivalent to an assignment statement in Lisp –and, if so, how. Figure 1 shows two students engaged in this discussion. $S4$ of this group made an initial comment (not shown in the figure): “We can define functions in Lisp using DEFUN, and they are stored in the D-list. When we call the function later, the Lisp interpreter will first find the function from the D-list, pair the actuals with the formals defined and store those in the A-list. In such a way, implicit assignment is made.” $S2$, on the other hand, had a slightly different take on the

matter. She explained that in imperative languages bits are manipulated in memory which are assigned some meaning by the programmer, whereas in functional languages, the programmer tells the computer “what things, actions etc. are”. She explained this with an example of Fibonacci numbers, and concluded, “So the approach in imperative is more algorithmic, whereas in functional we declare the steps instead of changing any variables state.”. These were S4 and S2’s posts, respectively, from R_0 . Upon entering R_1 , S4 sees S2’s above comment and *agrees* with it by clicking the green button. Then she modifies her own position (shown in italics in the figure) to acknowledge that a variable cannot be reassigned in `lisp`, unlike her initial claim.

The discussion continued for three days, with most students logging in for 30–40 minutes each day, at their time of convenience, reading their peers’ posts, formulating their responses to those, and posting those responses in the tool for that round. At the end, each student answered a quiz, which was essentially a description of how (s)he would implement this construct in Lisp, and posted a summary of the group discussion (s)he participated in. Feedback from the participants on their learning using the tool and various of its features was sought in the form of an anonymous online survey. 22 of the 39 students completed the survey. All 22 were graduate students of Computer Science and Engineering, 18 of them were males, 3 were females, and one chose not to disclose the gender.

On a question regarding each student’s perceived understanding of the topic on a scale of 5 (5 being the highest), the average understanding before the discussion was 3.5 (mode=3), which rose to 4.6 (mode=5) after the use of CONSIDER. While it is true that any intervention is likely to result in improved understanding, the comments by students on what might have caused this change in understanding highlight the benefits of our approach. For example, many students noted that they had not considered what might go wrong with their initial approach until someone in the group pointed it out; as a result, they were able to refine their answers. It is not possible for an instructor to point out such potential mistakes, let the student refine the answer, and again point out flaws, over and over again, for each of the 40-odd students in the class; nor can this happen efficiently unless students with conflicting ideas are grouped together. Another student commented: “Critiquing someone else’s implementation helped in optimizing my own approach to solving the problem.” Even a student who thought his understanding of the topic was at the highest level 5 both before and after the discussion conceded the usefulness of the approach, saying, “I had a good grasp on the topic from the start, but I was able to refine my answer—for this particular question—through the discussion.”

A considerable majority of the students felt that the approach provided an opportunity to understand the topic in depth, compared to the in-class discussions (Figure 2). Some of them cited short meeting times as the reason for not being able to get into the details of a topic while discussing in-class. While some students felt that CONSIDER gave them space for a *personalized* discussion where they could contribute comfortably (presumably a reference to the fact that some students are not comfortable participating in the in-class discussions), some others felt that instructor’s intervention would have been useful. One comment also mentioned that in-class discussions are “one time”, referring to

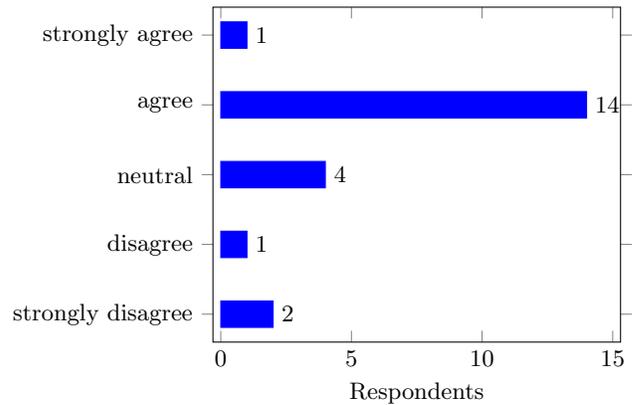


Figure 2: CONSIDER provides a better opportunity to learn compared to in-class discussions.

the short-lived nature of those, which is overcome by the online discussions recording all interactions.

The survey also asked students their feedback on the features of anonymity, rounds-based structure, and the duration and number of rounds used in the exercise. Pie charts in Figure 3 show student responses to each of those.

While a majority of respondents (59%) felt that three rounds were just about right for this discussion, in some groups the students came to the same conclusion in the second round itself, and the additional round did not seem to add much value. One respondent mentioned that one of his peers was not clear enough in his comments, because of which he felt another round might have been useful. An interesting suggestion received was that the tool can have an ability to get a vote from members of each group on whether they want to add another round or not, at the end of the second round, and add the third one if required. This could be a useful feature to be added in next version of our app. We would also like to mention that some students expressed having this assignment in the last two weeks of the semester made them pressured for time, as they had to spend about 30–40 minutes each day on this assignment for 3–4 days. We will keep that in mind when designing our next set of experiments.

On the duration of each round, which was 24 hours, there were expected responses with 73% of the students saying it was adequate. Although two students suggested having shorter rounds (12 hour), some other students commented that it should not be shorter since different people may have different schedules, and not everyone can find the same time of the day to log in and contribute to the discussion meaningfully. Some students also mentioned that 24 hours was good enough time for them to reflect on others’ comments and respond to it, without feeling rushed into it, as well as to not let their interest wane.

73% of the posters felt that anonymity of the posters, which is an important feature of CONSIDER, was helpful. Their comments on why they felt it was useful are in line with the reasons why we included it in the approach in the first place: it made sure that “answers were discussed without prejudice”, and not having anonymity “may lead to (personal) conflicts at times.” One of the two students who responded in favor of knowing the identity felt that way since it would allow them to continue discussing the topic in detail with the peer, even after the assignment is over. The

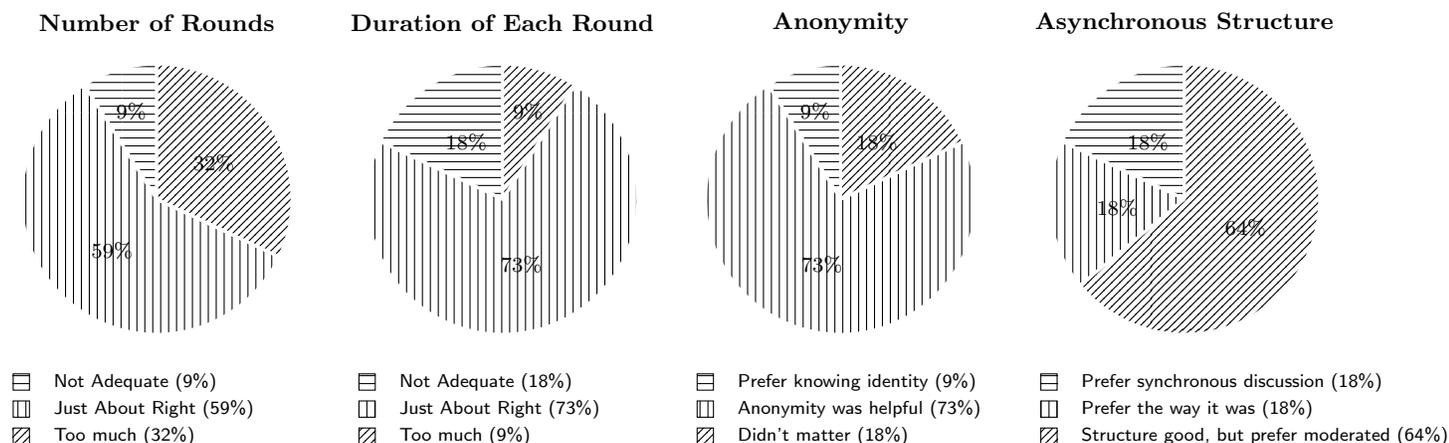


Figure 3: Survey responses on various features of CONSIDER

other student’s comment was along the same lines, but also hinted at a social advantage of disclosing identity, which we had not thought of. He commented that most students do not know each other, and some are shy of asking technical questions in class, but after engaging in discussions with a classmate for a few days, if they come to know who they are talking to, they may want to continue to collaborate with those even beyond this assignment or classroom. In future versions of CONSIDER, we may allow disclosing the identities of group members after the discussions, at the discretion of the instructor, possibly if *all* group members agree to it.

The asynchronous, rounds-based peer-discussion is another unique feature of CONSIDER. Reflections on this feature were rather mixed. Only 18% students liked it the way it was, while an equal number said they would prefer a synchronous discussion. Remaining 64% were ok with the structure, but preferred having the instructor intervene at some point of time. Some of them were okay with knowing the teacher’s opinion *eventually*, which, in the form of an in-class session to clarify any remaining confusion on the topic after the exercise is over, is a practice we would recommend. But some other students felt the need of getting the instructor’s feedback on *each* round. This would be essentially equivalent to grading 40-odd assignments *every day* for the duration of the activity, which is not practical. Let’s also look at another comment in this context. It advocates allowing members of a group to decide if majority of them disagree over a point, and ask for an instructor intervention “instead of arguing among themselves and wasting time.” In addition to the practical problem with instructor’s time mentioned above, we believe there is another, deeper problem reflected by such comments, related to what Rick and Guzdial [14] call a “lack of collaborative culture” in STEM education. These comments seem to reflect the widespread notion that discussing and arguing with peers about their conception of a technical topic does not (usually) contribute to learning. But this is contrary to our understanding of how learning happens, particularly in the case of collaborative learning, defined broadly as “a situation in which two or more people learn or attempt to learn something together” [4]. In their analysis of why their wiki-based collaborative learning environment was successful in English literature and architecture classes, but not in STEM courses, Rick and Guzdial [14] identified one of the reasons to be “competitive nature of the

courses and single answer questions”. The same is reflected here with the student trying to get to the (presumably one, correct) solution of the problem via the instructor, instead of trying to discuss with peers other possible approaches to the solution, an exercise he considers a waste of time. Consciously employing collaborative learning techniques in all levels of STEM education might eventually mitigate such issues, and would help see learners as well as educators the value of collaborative learning.

Nevertheless, there were students who appreciated the importance of collaborative learning driven by cognitive conflict, and of the emphasis on discussing the topics with peers. We would like to conclude the discussion on survey data by presenting a comment that reflects this understanding: “Since nobody is really expert like instructor, we have to provide strong evidence to convince others (as well as ourselves).” It is important to note here that, unlike the previous two comments which asked for the instructor to intervene in order to make sure they learn, this comment indicates that they learn better *because* the instructor is *not* present, resulting in them being more vigilant about the arguments they produce – this is *precisely* the point of collaborative learning driven by cognitive conflict.

5. CONCLUSION AND FUTURE WORK

We have developed a novel, online approach, called CONSIDER, that combines the strengths of conflict-driven collaborative learning and Computer-Supported Collaborative Learning. The unique features of our approach and their benefits are summarized in Table 1. We have implemented it as a scalable, platform-independent web application using Google App Engine and Python. We used it in a programming languages course for a homework assignment about implementing assignment-statement like capabilities to the functional language Lisp, in which 39 students participated. Preliminary analysis of the discussion data suggests that the approach was very helpful in improving the participants’ learning about the concept. At least two students in 9 of the 10 groups changed or refined their solutions, based on comments of their peers, during the course of the discussion. In some groups, it was observed that, as a student critiqued another student’s solution, he realized some caveats in his own solution and refined it. The only group in which only one student made such modifications had irregular participa-

Feature	Resulting Benefits
Small group formation based on cognitive conflict	The discussion in each group is driven by the conceptual disagreement among its members; attempts to resolve it would lead to deeper understanding.
Anonymous posting in groups	(a) Students participate more freely; (b) The effectiveness of the discussion is not compromised by any gender/ethnic/other preconceptions some students may have.
Asynchronous, structured rounds-based discussions	Each student, whether quick on her feet, or prefers to think through subtle ramifications before posting, or anything in-between, participates equally effectively.
Online record of the discussion	(a) Students can come back and refer to their discussions and can continue to learn from the experience. (b) Instructors can look at the interactions and decide if further explanation is required for the topic.

Table 1: CONSIDER: Features and their Benefits

tion by its members (some students missing the deadline to submit posts, etc.). It is not clear how to address the issue of participants “dropping out” of the discussion permanently or temporarily; one possible solution can be having a teaching associate as a dummy participant in each group, who can fill in for a missing student if the need arises – since each poster is anonymous, students will not know if the post is made by a student or a TA, and can continue with the discussion in the usual manner. We continue to analyze the generated discussion data to understand how our approach helps students in learning Computer Science and Engineering concepts.

22 students completed the follow up survey for reflections on how the approach helped their understanding of the concept. All of the participants shared very positive feedback, highlighting the importance of each of these features of CONSIDER. In particular, students considered the feature of anonymously posting comments extremely helpful in participating freely and posting without prejudices. While $18+64=72\%$ students were supportive of the asynchronous, rounds-based structure of discussions, 64% of them said they would prefer an intervention from the instructor, instead of discussing only with the peers. This opinion likely results from a lack of collaborative culture in STEM education, in which the value of collaborative learning, through discussing with peers, is not readily appreciated.

We plan to further evaluate the efficacy of the features of CONSIDER by designing careful experiments in coming semesters and using the tool in different classrooms. We are performing the study using the pattern of design-based-research [2]. This will have us engage in multiple, iterative formative assessments, and additional questions are likely to emerge as research questions are iteratively refined. This approach blends well with our software development pattern which is intended to follow an Agile process where features and functionality will be released and feature-by-feature testing will be done with end-users/learners.

After few more rounds of user testing and refinements, we plan to make our tool available as an open source software, which other educators can download and configure to use

in their courses. It will be highly customizable in terms of features such as number of rounds, type of questions, group size, etc., to suit their specific needs.

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