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Work-in-progress: A novel approach to collaborative learning in engineering programs

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Abstract

The importance of collaborative learning is well recognized. But *achieving* collaborative learning, especially in engineering (or, in general, in science, technology, engineering, and math (STEM)) courses, is challenging. Over the last several years, a number of online technologies that can be used to effect collaborative learning have been introduced. Especially promising are *wiki*s and programs in various disciplines have introduced wiki-based collaborative activities. But researchers have reported that, contrary to expectations, wiki-based activities have *not* resulted in promoting collaborative learning. The results have been especially poor in STEM courses.

Peer-instruction (PI) is a *classroom* technique that helps students help each other develop deeper understanding of important concepts and overcome common misconceptions. In this paper, we report on our on-going work that integrates PI ideas with the approach of wikis to develoop an online collaborative learning approach designed for STEM courses. We elaborate on the conceptual basis of the approach and situate it within the *Community of Inquiry* framework, detail our plans for using it in a number of engineering courses, consider the prototype implementation of a tool based on the approach, and our plans for assessing the approach.

1. Introduction

The importance of collaborative learning is widely recognized. Thus, for example, a central component of the *how people learn*[1] (HPL) framework is *community*. That is, according to the HPL framework, being part of a close-knit community of learners, actively interacting with each other, can be of great help to the individual student in developing his or her knowledge and understanding of the particular discipline; we will elaborate on HPL later in this section. Given this, and given the potential that online technologies provide for interaction and collaboration, a number of researchers have, over the last several years, explored ways to exploit such technologies to effect collaborative learning. These researchers have developed a number of tools and techniques, some of which we will briefly review later in the paper, and demonstrated their use in a variety of disciplines and settings ranging from K-12 through college programs. Especially promising are *wiki*s and wiki-based collaborative activities.

In spite of all this work though, *achieving* collaborative learning, especially in engineering (or, in general, in STEM) courses, has been challenging. Indeed, contrary to expectations, and contrary to their success in other disciplines, researchers have reported[2] that wiki-based activities have *not* resulted in promoting collaborative learning in STEM courses. Both students and faculty have shown little or no interest in using the approach in their courses. We will see further details later in the paper; for now, we note that faculty have been reluctant to use the approach because of the additional work that would be needed to develop materials and activities that would be relevant for their courses and be approrpriate for the medium; students, despite their reliance, almost to the point of addiction, on interactive social media in other walks of life, have been even more resistant to on-line collaboration in their STEM courses, preferring even to having their grades penalized rather than participating in such collaboration. There *have* been some reports of successful wiki-usage in engineering courses. But, as we will see later in the paper, the activities involved in these reports tend to be primarily non-technical, e.g., engineering writing, etc.

Peer-instruction[3] (PI) is a *classroom* technique that helps students help each other develop deeper understanding of important concepts and overcome common misconceptions. It has been used in a number of STEM courses by a number of different instructors in several colleges and universities and shown to be very effective[4,5,6] in these courses. At the same time, as we will see in Section 3, PI does pose some challenges; e.g., it requires some class-time to be devoted to PI activities, requires the instructor to be comfortable with organizing and conducting the activities, certain kinds of topics may not easily lend themselves to the approach, etc.

The goal of our work is to develop an approach called *PICOLA* (for *Peer Instruction-based Collaborative Online Learning Activities*) that borrows some ideas from PI and integrates them into an approach for collaborative on-line learning and implements the approach in a system that can be used in a natural and effective manner in a variety of STEM courses. In our on-going work, we are implementing a prototype of the system and intend to use it in a number of *computer science and engineering* (CSE) courses. We plan to use the results from these courses to iteratively fine-tune the approach and the system; and then use PICOLA in a broader range of engineering courses.

As we will see, PICOLA is consistent with the essential learning principles embodied in the HPL framework[1,7,8,9]. Figure 1 depicts a pictorial representation of the framework, based on one in[1].

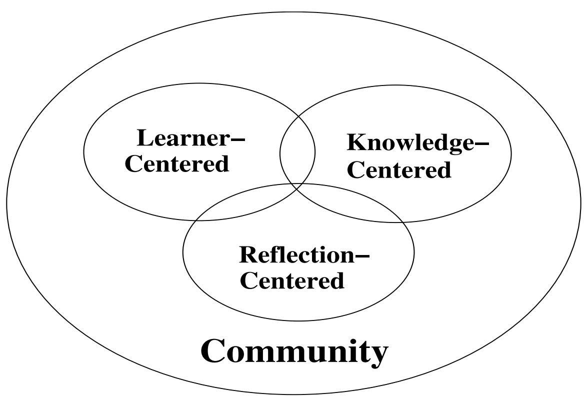

Figure 1: HPL Framework for Learning Environments

According to HPL, the learning environment and activities should be designed to be:

1. *Learner-centered*: Account for the knowledge, skills, preconceptions, and common misconceptions of the learners;
2. *Knowledge-centered*: Help students learn with understanding by thinking qualitatively and organizing their knowledge around key concepts;

3. *Reflection-centered*: Find ways to monitor progress and provide formative, timely feedback to help students be aware of their own understanding and gaps in that understanding;
4. *Community-centered*: Foster norms that encourage students to learn from one another.

In the PICOLA approach, as we will see in Section 3, learners will be grouped into communities that are organized based on their prior knowledge and skills, to work on specific problems that are organized around key concepts. The PICOLA system will enable and encourage the students to challenge each others' ideas and approaches and learn from one another. The system will allow instructors to monitor student progress and provide appropriate and timely feedback; and allow students to reflect on their own work, compare them with the work of their peers, and identify problems in their understanding and work toward addressing them.

The rest of the paper is organized as follows. In Section 2, we review related work and consider various approaches and systems that have been developed for on-line learning. In Section 3, we develop the PICOLA approach as a novel combination and extension of ideas from PI and wiki-based systems; and situate it within the *community of inquiry* framework[10], a framework designed to analyze as well as help the development of on-line learning communities. In Section 4, we describe the prototype PICOLA system. We conclude in Section 5 by summarizing our approach and describing our future plans including plans for assessment.

2. Related Work

A number of different approaches have been developed, over the last three or four decades, to exploit IT tools and systems in education at all levels from K-12 to undergraduate engineering programs through corporate training. Below, we review a handful of these systems.

Recent work in cognitive science has focused attention on learning and cognition and such questions as how information is stored in the brain, what happens when a learner's skill with a particular topic increases, etc. A framework for these developments was provided by the work of Anderson[11]. Several systems have been built based on this framework, most notably the *automated cognitive tutor* (ACT) system[12].

Merrill and others[13] introduce the concept of *instructional transaction*, the set of interactions necessary for a student to acquire an item of knowledge or skill. The idea is to identify specific patterns of transactions and develop algorithms that implement them. The algorithms are based on three types of instructional strategies: presentation (of information); practice (working on problems of varying difficulty); learner guidance (in the form of feedback). These algorithms work with entities known as *knowledge objects* (KOs). The claim is that, given appropriate KOs, suitable transactions based on the intended learning outcomes can be defined. A general software "engine" can perform these transactions in the appropriate fashion. *Learning objects* can be considered a generalization of knowledge objects and various systems based on learning objects have been built[14].

Mayer[15] uses the term "multimedia learning" systems to represent the fact that in many of these systems, learning involves multiple streams of input to the learner, for example, words on a screen, pictures or animations, a voice reading some information, etc. The work in this area identifies key principles that should be adhered to if multimedia learning systems are to be effective in achieving effective learning in various domains. For example, the *split-attention principle* states that it is important to avoid formats that require learners to split their attention between, and mentally integrate multiple sources of information. Ayres and Sweller[16] present an example: a geometry problem is presented as a diagram showing a polygon with additional internal lines with vertices labeled with various letters; a textually *separate description* specifies the angles of the polygon using the vertex names listed in the figure. This requires the learner to move attention back and forth between the figure and the text description - a violation of the principle.

Scardamalia and Bereiter[17] make the case for what they call *knowledge-building*, as against *knowledge-reproduction*, in educational programs. Knowledge-building focuses centrally on the development of deep understanding as against simply memorization and organization of knowledge. Their goal is to build systems that will allow students to actively construct knowledge rather than "cast the student into the role of recipient of knowledge". The CSILE system of Scardamalia *et al.*[18] was designed with this idea in mind. The approach of the CGTV group[19] has some similarities to the CSILE system. The key point of this work is to situate learning, via problem solving, in the *context of realistic problems* rather than present one issue at a time to the learner.

While each of the above approaches and systems and the many others that we have not mentioned has its own particular goals, they can be broadly classified into two groups, *knowledge-centered* and *activity-centered* approaches respectively. The central focus of knowledge-centered approaches is on items of knowledge and ensuring that students acquire the knowledge in question. Examples of systems in this group include the ACT system[12], the work of Merrill *et al.*[13], and systems based on learning objects[14]. By contrast, the focus of *activity-centered* approaches is on such student activities as collaborative team-work, building models of various kinds in constructionist[20,21] systems, and having students engage in *reflection* via such activities as maintaining *portfolios* of their work, etc. The intent is that these activities will help students develop deep knowledge and understanding of the topics of study; but the main focus, nevertheless, is on the activities. The CSILE system[18], the systems of the CGTV-group[19], and *mindtools* of Jonassen[22] fall in this category.

Although the ultimate goal of both groups is to effectively exploit IT tools and systems to improve education, the difference in focus has lead to considerable discussion and debate about their respective effectiveness; see, for example, papers by Greeno and others[23,24] for the activity-centered group's arguments and papers by Merrill and others[25,26] for the knowledge-centered group's counter-arguments. Sfard[27] frames the debate in terms of the *acquisition metaphor* (AM) versus the *participation metaphor* (PM). In AM, we think of knowledge as something the learner wishes to *acquire* from such sources as a teacher, books, or the Internet; in PM, we think of a learner as a *participant* in such activities as reflecting, communicating, inquiring, building models, etc. The HPL framework, as we saw in Section 1, stresses the importance of both considerations.

3. PICOLA Approach

The key motivation behind our work is to enable, even ensure, that students, in small groups, engage in appropriate activities related to specific topics in standard undergraduate engineering (more generally, STEM) courses to help themselves and others in the group develop a deep understanding of the topic in question. Further, the system should enable students, on their own (i.e., individually), to engage in appropriate reflective activities that helps them see the connection between the particular topic and earlier topics in the course and possibly in prior, prerequisite courses to further refine that understanding. And, finally, should allow the instructor and teaching assistants to provide timely feedback to both individual students and groups of students at appropriate points. Moreover, the system should be relatively easy to use for the students, the instructors, and the teaching assistants since otherwise it is not likely to be used.

Although systems such as CSILE[18] and those of the CGTV group[19] do have some of these characteristics, they are designed for use in K-12, the activities being organized around major themes (such as sustainability). Thus they are not entirely suitable for use in standard undergraduate engineering courses. Moreover, they use specialized software requiring a fair amount of effort on the part of the students and the instructor. *Wikis*[28] are more promising and indeed a number of courses, including engineering courses, have tried using them. At the same time, as noted earlier, although wikis seem to have been effective in courses devoted to developing students' writing skills and the like, their use has not resulted in collaborative learning in standard STEM courses. We will consider the reasons for this below. One of the key problems, as we will argue, is that while the systems used in these attempts do *allow* students to collaborate, they do not provide an appropriate framework organized around individual, relatively small, topics in the course to *ensure* such collaboration. The PICOLA approach is designed to address this weakness and will help make collaborative learning a reality in standard engineering courses.

3.1 Wikis

The most common view of a wiki is as a website that allows its users to add, modify, or delete its content via a browser using a simple editor. Hence a group of individuals can work together to create a wiki site that thoroughly explores a particular topic. It is this type of wiki that Cress and Kimmerle[29] consider when they show how developing such a wiki can help the people involved in the development to enhance their individual knowledge and understanding of the topic by an iterative and interactive process. While this approach is useful in, for example, a community of practitioners constructing (or reconstructing) knowledge, it is less suitable for the typical undergraduate STEM course where a number of (related) topics and concepts have to be discussed in a relatively short period of time. Wikis can, however, be used in many other ways. As Larusson and Alterman[30] note, "Wikis are *plastic*. It is easy … to support a variety and range of collaborative learning activities … using the wiki structure as a mediating organization for how students interact and coordinate their collaboration." It is the ability of wikis to mediate student interaction and collaboration that makes them potentially capable of promoting collaborative learning in courses and has been the motivation for their use in a wide range of undergraduate programs.

Unfortunately, however, a number of authors have reported on the failure of wikis to live up to their promise of ensuring collaborative learning. Before considering these issues, it may be worth noting here a minor debate in the literature concerning terminology, specifically the distinction between *collaborative* learning and *cooperative* learning. For example, Dillenbourg *et al.*[31] define cooperation as the *division of labor* between individuals in carrying out a joint activity, while collaboration involves the *mutual engagement* of the participants in a coordinated effort to solve the problem. Most other authors also use this same terminology although some, e.g., Olivares[32], exchange the two terms! In this paper we will follow the more common practice and use collaborative learning to mean a group of students working together to learn a particular topic or concept with the activities of the group helping *each* of its members acquire that knowledge.

Cole[33] reports on the experience of using a wiki to promote collaborative learning in an undergraduate course on *information systems*. The course, with a cohort size of 75 students, was organized so that the lectures were in alternate weeks with students being given time in the other weeks to discover new material and post to the class wiki. There was an added incentive for the students to post to the wiki since they were told that one quarter of the questions on the final exam would be based on the material that they posted. The expectation was that students would not only post content but edit each other's posts and engage in collaborative learning. Cole reports that after five weeks (halfway through the course), there had been *no* posts to the wiki! Volunteer group interviews with the students elicited such reasons as lack of time or pressure of other work, etc.

Leung and Chu[34] report on the results of the use of a wiki for collaborative learning in an undergraduate course on *knowledge management*. The class had 21 students in it, divided into four groups, each with a group leader who was responsible for coordinating the group's work. Each group had to use a wiki to work on its project. In all of the groups, most of the contributions, by far, were made by the group leader; in one case, the group leader's contributions to the wiki was almost 90% of the total! Judd *et al.*[35] report similar findings from a large undergraduate course on psychology with an enrollment of nearly 800 students, divided into groups each of size 20 to 30 students. Each group was required to use a wiki to engage in a collaborative learning activity related to the concept of *motion detection* and create a (group) submission. Students were *required* to meet certain specified minimum contribution requirements. While the *letter* of the requirements was satisfied by over 80% of the students, the *spirit* was satisfied by very few. Although each group had nearly 7 weeks to work on its wiki, nearly 70% of the contributions by the various students in the group occurred in the last three days with less than 1% of the students contributing over five or more days to their group's wiki. Judd *et al.* also note that about 10% of the students (across various groups) made comments on various wiki pages. Of those, about 20% were considered to have a collaborating learning component; in other words, 2% of the students made such comments.

Rick and Guzdial[2] present perhaps the most compelling evidence of the failure of wikis to effect collaborative learning in STEM courses. Since wiki software was still evolving when they started their work, they created their own version, *CoWeb*, for use in courses at Georgia Tech. Over the years, they worked with faculty in four different disciplines to introduce CoWeb-based collaborative learning activities in their courses. In architecture and english composition classes, the results were very positive. Indeed, the use of (a specialized) CoWeb has become a regular and permanent feature of many architecture courses. Similarly, in the english class, the CoWeb section did significantly better than the comparison section with respect to all relevant metrics. By contrast, Rick and Guzdial report, "[a]doption in STEM classes has been overwhelmingly disappointing". In one attempt to encourage collaborative learning, they created a wiki space that a class in calculus could share with a class in engineering, the idea being that engineers would see the need for calculus to complete their work and the students in the calculus course would see that the content they were learning would be applicable in their later engineering courses. A mandatory assignment required students in the chemical engineering course to create simulations that generated data for the math students to analyze and report back. Fully 40% of the students preferred to accept a zero on the assignment rather than collaborate with the chemical engineers! Rick and Guzdial conclude (as do the other researchers whose work we have summarized above as well as many others) that there are strong cultural barriers to collaborative learning in STEM courses, no matter how effective the medium might be.

Rick and Guzdial do present what they argue is an exception. They designed a new introductory course in *media computation*. This course introduced concepts similar to those in standard intro computing courses but using media-related examples. They created a CoWeb site where students in the course could create their own home pages; included design galleries on which students could post their creative media work; etc. A key idea was to design assignments that offered opportunities for creativity and sharing, e.g., create a collage by manipulating an image by using software tools for color modification, cropping, etc., and combining the various versions into the collage. Students would then share their collages with their peers in the gallery page. Students participated enthusiastically in these activities, with students sharing many artifacts (visual collages, audio collages, digitally created animations, etc.) on the gallery pages. But it is not clear that this is collaborative learning of *computing concepts* (such as iteration or recursion etc)[1]. In the case of the architecture course at Georgia Tech, one of the main points of the course was to help students develop skills to design various structures. Hence, a gallery of designs they produce and the resulting comments, suggestions for changes, etc., would help the students' growth as designers and architects. By contrast, the point of the computing course is to help students develop an understanding of important concepts such as iteration and recursion, and the ability to apply them appropriately to develop software. Hence a "gallery" that displayed the *software* that students developed in the course would be analogous to the display of building designs produced by architecture students and would help the computing students evolve toward becoming computing professionals. By contrast, a gallery that displayed visual collages created by their software does not say anything about the quality of the software itself and will not help students in their computing skills. Thus the question is, how do we ensure that students engage in collaborative learning *focusing on the important ideas and concepts*, rather than incidental, if attractive, artifacts such as collages of attractive images etc.? We believe the answer is to create on-line collaborative learning activities based on ideas from *peer instruction*[3], as we see next.

[1]It must be noted, however, that students completed this course successfully at a much greater rate than students taking other intro computing courses. Hence, if nothing else, the approach ensured that the students were engaged in the course.

3.2 Peer-Instruction

Peer instruction[3] (PI) is a classroom technique that helps students help each other develop deep understanding. Briefly, PI works as follows: The instructor poses a conceptual, multiple-choice question. Students work individually for 3–4 minutes and submit their answers via a *clicker*-like device. They then turn to their neighbors and, in groups of 4 or 5, discuss the question, each trying to persuade the others of the correctness of their own answer. During the discussion, the instructor may circulate around the room, eavesdropping on various groups. After a few minutes discussion, each student resubmits the answer which may or may not be the same as the one submitted before. A quick look at her monitor tells the instructor how well the class understands the concept and helps guide the class discussion that follows.

Use of the approach in many STEM courses has shown that the discussion among students helps many more to change from wrong to right answers than the other way[4,5,6]. But there are a number of issues. If most students in a group, i.e., students who are sitting next to each other, came to the same answer individually, they will not have much to discuss. Second, if one student in a group is very vocal, he/she may dominate the discussion. Students who speak only after careful thought may never get a chance to speak and may end up not contributing to the group's discussion. Third, the learning is limited to items that can be phrased in the form of multiple-choice questions that students can answer relatively quickly. Fourth, PI can be disruptive to the lecture and can require the instructor to be fairly gifted in handling a class with a large number of groups simultaneously engaged in discussions.

3.3 The PICOLA Model

The essential idea underlying the PICOLA model may be summarized as follows. A key part of STEM courses are homeworks/assignments of varying difficulty. We organize each assignment into two parts. The first is a *background part*, which we abbreviate to *BP* for convenience. BP will be similar to a PI question of the type described above. The BP will be posted to each student's on-line page at a specified time and the student will be required to submit an answer to the system within 24 hours. Based on the submitted answers, the on-line system will automatically form groups of 4–5 students each, each group containing students who picked different answers[2] so that each group has students who picked a range of different answers for BP. Each group will receive a link to a page that summarizes the various answers that students (including students in *other* groups) have come up with for BP. The page will also contain links to the home pages of each student in the group and their contact information so students in the group who do not know any of the others in the group can get acquainted[3]. The group then discusses, in a discussion forum created *for that group for that problem*, the various answers with the goal of trying to explain each one, i.e., for each answer the group should posit an explanation for why a student might have come up with

[2]If a student does not submit the answer within the specified time, he/she will be assigned to a group randomly with no more than one such student in any group; and a record of this will be maintained so that the instructor can take appropriate action in the case of repeat offenders.

[3]It may, however, be interesting to see whether the groups will be more effective if students did *not* know the identities of the others in the group. This is a research question that we plan to consider in our work.

the particular answer; and if different group members have different explanations, they should try to arrive at a consensus. This discussion must be summarized by one of the students in the group in a page that he or she creates, the responsible student being identified in the original message that the group received. The on-line system will ensure that each student is, on the average, assigned this responsibility for every fourth such activity. The group will be required to complete this task within 3 days. During the next class meeting, the instructor will lead the class in a discussion of the BP, the various possible answers, calling upon students from individual groups to explain the particular group's explanation of particular answers. The result should be a thorough discussion and clarification of the underlying concept.

Immediately following this class meeting, each group will receive a link to a page that describes the *main portion* (MP) of the assignment which will typically be a substantially more detailed one than BP. *Conceptually*, MP will typically involve not only the main concept underlying the corresponding BP but also earlier concepts from the course and, possibly, related concepts from prerequisite courses. As in the case of the BP, a discussion forum for the particular group for the particular MP will be created by the system and a link to the forum sent to the group. The group will then work on the problem over the next (typically) 15 days. The exact approach that the group will take will, naturally, depend very much on the particular problem. But, in each case, on days 4, 8, and 12, individual students will create a *summary* page that summarizes the group's discussion thus far. Which particular student in the group is responsible for which summary will be specified in the original message that the group receives. The fourth student in the group will serve as moderator for the group's discussion (and the system will ensure that each student in the class plays each of these roles). Each group will submit a single final answer page at the end of day 15 but each student in the group can include an additional comment expressing, e.g., his disagreement with the group's conclusion/answer and his/her rationale. In addition, the fourth student in the group (the moderator for the group for this MP) will be required to produce a final summary to be submitted immediately after the 15 days are up. Grades will, typically, *not* be the same for all members of the group. In particular, the quality of the summary that each student is responsible for will be worth about 30% of that student's grade on the assignment. The quality of the student's contributions to the discussion forum during the 15 days will be worth another 15-20%. Naturally, these details will vary from course to course and even from one assignment to the next in the same course; but the broad structure will be as specified above.

Each student in the course will also have a private page that will contain links to his/her previous work on prior assignments in the course (and, in the longer term, prerequisite courses as well). These will be to pages that are essentially copies of the work that each of the groups that the student was part of when working on both the BP and the MP of each of those assignments. In other words, each student will have access to a repository containing all of the work that the groups he/she was part of for each of the prior assignments. When a group receives the page specifying the MP for the next assignment in the course, each student in the group will also receive links to those parts of his/her repository related to assignments that dealt with the same or closely related (or prerequiste) concepts. This will enable the student to go over that material carefully in preparation for working on the new assignment. This is somewhat similar to *e-portfolios* except that the student will have access to the most relevant portion of his/her past work when working on a new assignment. Moreover, the student will have access to not just his/her answers to previous assignments but also the contents of discussion forums that his/her groups created in the various items of past work and, even more importantly, the *summaries* of those discussions created by the various students in those groups. And the PICOLA system will do all of the work required to maintain the repositories and providing the links to the most relevant parts of the repository, etc., allowing the student to focus on the engineering (more generally, STEM) topic, rather than worrying about routine work in saving and accessing the information. Further, *instructors*, following the completion of each assignment will be able to read the summaries of the discussions created by the students in the various groups and look for common misconceptions which can help tailor the future direction of the course or, possibly, the way the course is taught in future offerings.

4. Prototype System

We are currently in the process of implementing a prototype version of the PICOLA system. This is the design/implementation project in the capstone design course in our Computer Science and Engineering (CSE) program. Thus the students who will work on the prototype are CSE majors who are in the final semester of their programs. Most of these students have extensive experience in implementing large scale software systems as part of their internship experiences over the last few years. Moreover, since they have just been through much of our undergraduate program (including non-CSE STEM courses such as calculus, physics, etc. that are required as part of their CSE curriculum), many of the students will have well-informed opinions about what facilities are likely to be most beneficial to students going through these courses and should be included in this first version and what facilities can be left to future versions[4].

Once the prototype is complete by the end of the current semester, we will test it out in two junior-level courses in our CSE curriculum. The first is a course on the concepts of programming languages, the second a course on software engineering concepts. Both of these courses have a number of conceptual issues as well as more detailed issues that students often have difficulties with and that a well designed system that enables collaborative learning can help address. Indeed, several of the more detailed issues in the courses that students have difficulty tend to be directly related to the earlier conceptual issues in the course. In-class discussions in these courses show that, following such discussions, many students, *especially those who participate actively* have a somewhat clearer understanding of the concepts and issues involved; but the students who do not participate tend to remain somewhat lost. Thus having each student in a small group with other members of the group having varying understandings of the basic ideas (the “BP” of the last section) and requiring them, as PICOLA will, to engage in discussions that each student is required to summarize at appropriate points will enable all students to develop a good understanding of the material. At the same time, as noted at the end of the last section, cases where an entire

[4]At the same time, many software engineers, especially early in their professional careers, tend to get carried away and implement features simply because of their technical novelty rather than because they provide justifiable added value to the users of the system. We will return to this point shortly.

group has difficulties even after their extended discussion, will help the instructor identify potential weaknesses in the manner in which the material is presented and developed in the course or in prerequisite topics, etc. PICOLA will enable this by saving copies of the discussion forums and, more importantly, of the discussion summaries in addition to the actual solutions submitted by each group.

It may be useful to illustrate this with a detailed example from one of the courses in our CSE curriculum, the junior level course on the concepts of programming languages. A key intended learning outcome of this course is for students to be able to *implement* simple programming languages. Specifically, given the formal syntax of the language, in the form of its grammar, and given a description of the intended semantics of the various constructs in the language, the student should be able to use the *recursive descent* approach to implement an *interpreter* for the language[5]. In order to achieve this outcome, the student has to achieve three sub-outcomes. First, the student must be able to analyze the requirements expressed in the productions of the grammar and map them to the structural requirements that programs in the language are required to satisfy. Second, the student must be able to construct and work with programs organized in the form of a collection of mutually recursive procedures where each one has a well-defined task which can be achieved, for the most part, by calling some of the other procedures (in some cases repeatedly) at appropriate points and in the right order and combining the results in appropriate ways as dictated by the task. Third is the ability to, in effect, combine the first two abilities; i.e., map the given grammar for the language to be implemented to the structural requirements that the constructs in the language must satisfy and, based on that and on the intended semantics of the constructs, create a set of mutually recursive procedures to parse and execute programs in the language. Indeed, in a sense, this third outcome really represents the overall desired outcome.

Typically, CSE students who have a strong mathematical inclination but do not, as a rule, enjoy coding, tend to be good with the first outcome. Other students with a somewhat weaker mathematical inclination but with a greater interest and experience with writing code tend to be good with the second outcome. Of course, it may not be possible to classify individual students as being entirely in one category or entirely in the other; it is more of a spectrum with students ranging

[5]For readers without a CSE background, a brief explanation of the terminology may be helpful. An *interpreter* for a programming language is an implementation of the language which, given any program in the language, *parses* the program to check that it confirms to the requirements specified in the grammar; and, assuming it does, constructs a parse-tree representation of the program. It then *executes* the program (represented in the form of the parse tree). In the widely used *recursive descent* approach to language implementations, both the parser and the executor are structured in a way that mirrors the structure of the grammar. That is, corresponding to each type of construct in the language, represented as a *non-terminal* and the corresponding *production* in the grammar, there is a procedure in the parser/executor that is responsible for parsing/executing *all* occurrences of that construct and *only* occurrences of that construct. The power of the approach comes from two factors. First, much of the detail in each of these procedures is dictated by the corresponding production rule in the grammar and, in the case of the executor, by the intended semantics; thus, once these are specified, much of the interpreter's detail is easily arrived at. Second, since each procedure corresponds to a single non-terminal and its production, the code for it tends to be relatively small and simple with each occurrence of a non-terminal in the production being represented, in the code, by a call to the corresponding procedure. Thus the procedures in the interpreter tend to be no more complex than the corresponding productions in the grammar.

from very strong with respect to the first outcome and relatively weak with respect to the second, or vice-versa, and those with intermediate abilities with respect to each outcome.

This is precisely the type of situation where collaborative learning can be of enormous value. If students in the course were organized into teams of 5–7 students each, with students in each team being at different points in the spectrum described above, and assigned to work on a team project of implementing a recursive descent interpreter for a programming language with a given formal grammar and the semantics of its constructs, the collaborative work with each team member bringing his/her special skills to the project will contribute to all the team members achieve the desired third outcome. The first task then is to identify, approximately, where each student in the course lies on the spectrum so that teams, each with a suitable mix of students, can be formed. This, as described in the last section, is the purpose of the BP phase in the PICOLA approach. But the situation here is a bit more involved since we have to judge students with respect to two distinct outcomes. Thus the BP will have to be substantially more involved than the type of multiple-choice question that is used in PI[3]. And it is not simply a matter of having more than one multiple-choice question but also that in some cases, for example in the case of the second outcome, the ability to construct and work with programs consisting of several mutually recursive procedures, this type of question would be inadequate. We won't go into the details of the specific questions we plan to use in different courses but it is worth pointing out that such more detailed questions, as against multiple-choice questions, fit well with the PICOLA model because a central component of the model are the discussions that student teams have to engage in after individuals submit their answers to the BP questions; as well as the summaries of these discussions that individual students are required to create and post. While well-designed multiple-choice questions can indeed result in useful discussions, we expect that such discussions will be very natural for the more detailed questions designed to assess student abilities with respect to the kinds of outcomes we have considered above. At the same time, multiple-choice questions have the distinct advantage that the system can automatically and immediately form student groups based on the individual student's answers. This is an essential requirement for a class-room based technique such as PI but it is not so important for PICOLA. Indeed, since different individual students will, in the PICOLA approach, submit their answers at different times (within a 24-hour slot), a student's group cannot, in any case, be determined as soon as he/she submits the answer. We will ensure that student teams can be formed within about 24 hours after the deadline for submission of the answers; but our key concern in designing the questions in the BP component will be ensuring that they will help us assess the students' abilities with respect to the relevant outcomes with good accuracy rather than being able to automate the grading. This means that the TA or the instructor for the course will have to grade the student submissions for BP relatively promptly, so student teams are formed in a timely manner and the teams can start their discussions as described in the last section.

In their work on team-based learning, Michaelsen and colleagues[36,37] identify several key factors that are important to ensure that all students in a team benefit to the greatest extent possible in achieving the intended outcomes. One factor they identify is the importance of *group identity*; i.e., they show that it is important for each member to feel invested in the success of the group as a whole. One way to achieve this is for each team to critically assess the work of the other teams.

In their class-room based approach, Michaelsen *et al.* have each team put up a poster summarizing its work on the classroom wall; the members of each team prowl around the room looking at the other teams' posters and trying to identify important deficiencies in the work of those teams; the team then writes up a critical assessment of the other teams' work and the quality of this write-up contributes to the grade of each member of the team, with each member in the team receiving the same grade. This kind of activity has been shown to contribute considerably to team learning. A second factor is ensuring that the team project is not of a nature that lends itself easily to be partitioned into essentially independent pieces that can be done by the various members of the team; and this will clearly *not* help students in the team learn from other members of the team. The PICOLA approach and model are designed to take account of such factors. Thus, for example, the summaries of discussions, created by each team, will, at an appropriate time, be made available on-line to all the teams. Each team will then be required to provide a critical assessment of the other teams' summaries. The quality of these assessments will contribute to the grades of each member of the team providing the assessment. This should be more effective than the classroom version since each team could take time to critically analyze the other teams' reports rather than having to scan as many posters in as short a time as possible. We will report on the results in future papers.

We will conclude this section by situating the PICOLA approach in the *Community of Inquiry* (CoI) framework[10]. The framework attempts to identify the key components of educational experience that are particularly important in ensuring an effective collaborative learning experience. It is somewhat similar to the HPL framework but while HPL is concerned with various aspects of how people learn, the CoI framework is concerned with what should be included in the educational experience that students go through to help them engage in effective collaborative learning.

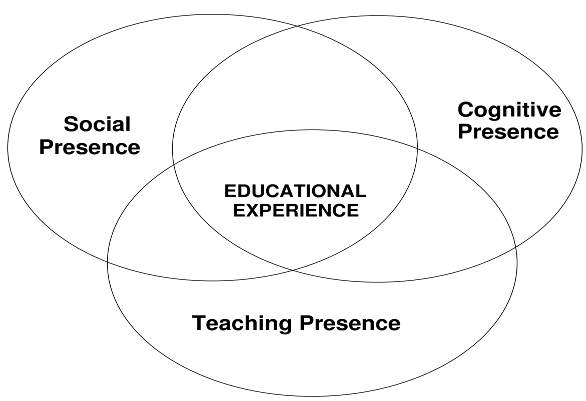

Figure 2: Community of Inquiry

Fig. 2, based on one in Swan *et al.*[38], depicts the CoI framework. The three principal elements of the CoI model are social presence, cognitive presence and teaching presence. Social presence may be defined as the degree to which participants in the learning environment feel affectively connected one to another; cognitive presence represents the extent to which learners are able to, via interactions with each other, construct and refine their understanding of important ideas through *reflection* and *discussion*; and teaching presence is the design of various instructional activities such as lectures *as well as* activities intended to facilitate interactions among students to help their learning. PICOLA contributes to all three. The main activities described above clearly are instructional activities designed to help students develop strong understanding. The interactions with other group members and summarizing discussions etc., involves both reflective activities as well as deliberations with group members. And the strong group interactions helps the students connect to each other at an emotional level. Thus the PICOLA approach is very consistent with the tenets of the CoI framework.

5. Conclusion

Some recent approaches to exploiting IT technology to improve education has focused on such approaches as using streaming video and the like. However, as Collison *et al.*[39] argue, "Text-based asynchronous communication is well suited for goal-oriented dialog and learning environments. No one is left out of a fast-moving conversation or is silenced because he or she is not called on. The reverse is also true, in that the excuse of running out of time as the bell rings is no longer available to participants … and absence from dialog or shallow interaction shows up quite clearly in … text format … A medium that supports learners' ownership of dialog and their active engagement with content is certainly a good thing." PICOLA is designed to effectively exploit these strengths of a simple text-based wiki-like approach. In practice, unlike more high-tech tools such as streaming video, PICOLA will disappear into the background and leave the focus on students' collaborative learning.

We conclude with a couple of pointers to ideas for future work with PICOLA (beyond what we have already described in Sections 3 and 4). First is one related to *assessment*. Rick and Guzdial[2] report on assessing the use of their CoWeb in their media computation course by comparing the percentage of students who completed the course successfully with the percentage of students who completed standard introduction to computing courses. We intend to adopt a somewhat similar approach for assessing the effectiveness of PICOLA. Consider the concepts of programming languages course that, as mentioned in Section 4, will be one of the two courses in which the system will be initially used. Several sections of this course are offered each semester. Hence we can compare the performance of students in a particular topic one section of the course that uses the system with that of students in the other section that does not use the system. We can also use the system for one topic in one section and not use it for the same topic in the other section of the course, and then reverse the two sections for the next topic; etc. Indeed, we can even compare the performance of students in a given section on one topic with their performance in a second topic with PICOLA being used for the first topic and not for the second. Such an approach will allow us to get a fine-grained assessment of what kinds of topics will benefit most for the use of the system and what kinds of activities are best suited for it.

At a more conceptual level, Hewitt[40] and Ioannou[41] propose a classification of on-line discourse into distinct categories based on the type of contribution a given piece makes to the overall discussion. Thus Hewitt argues that a contribution might be *standalone*, i.e., does not build on the ideas in other notes in the discourse; *add-on*, i.e., builds on the ideas of one other note; *multiple* *reference without convergence*, i.e., references two or more previous notes but not in a way that attempts at convergence; *convergent*, i.e., one that discusses some of the ideas and ties together two or more ideas previously discussed in the thread. The idea in PICOLA of requiring each student in a group to *summarize* the discussion thus far was indeed inspired by this categorization. It is these convergent contributions that really seem most important for the purposes of collaborative learning. But there may be additional categories of contributions; indeed, some of these categories may even be discipline-specific. In our work we will analyze the students' contributions in the discussion forums, see how they are related to the final solutions they arrive at, and try to identify such categories. Once we do that, we will be able to refine PICOLA to nudge students toward engaging in the most effective kinds of communications to best effect collaborative learning.

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