Resolving Differences: Twists and Turns in a Quasi-Synchronous Online Collaborative Mathematics Problem-Solving Session

Ramon Prudencio S. Toledo, Alan R. Zemel, Gerry Stahl

Drexel University, 3141 Chestnut Street, Philadelphia, PA 19104
Ramon.Toledo@drexel.edu, arz26@drexel.edu, Gerry.Stahl@drexel.edu

ABSTRACT:

Whether mathematical problem solving is done face-to-face or through computer-mediated communication, as long as there are multiple participants with their respective approaches, procedures and assessment methods, there is a need for participants to resolve their differences, whether through negotiation, argumentation or some other interactional activity to initiate, maintain and conclude their collaborative problem-solving activity. When this collaborative problem solving is conducted in the quasi-synchronous environment of chat, where all communication is conducted through text, participants engage in artful ways which use the affordances of chat to engage in the achievement of shared resources, decide problem approaches as well as their order of use, assess the validity of proposed approaches and determine the appropriateness of proposed solutions.

INTRODUCTION

A research challenge

When problem-solving is done face-to-face by a group, participants demonstrate to other participants how they define, understand and solve the problem (Herring, 2001). Participants make visible to each other what, how and when they are thus engaged in problem-solving, even if what is demonstrated is incomplete or inaccurate. Making the process visible is necessary to enable other participants to concur, disagree, modify or contribute in some way to the definition, understanding and solution of the problem. In a face-to face situation, making visible may involve both spoken word and physical gesture. When problem-solving is done online, participants see only what the computer application that they are using, allows them to see. Whatever is seen, heard or read by each participant is dependent on the features of the application being used.

Though participants in a quasi-synchronous online collaborative problem-solving session make their knowledge visible in order to make it possible to collaborate, there is no a guarantee that it is immediately possible to determine how participants resolve their differences with respect to their definition, understanding and solution of a problem they are solving. Participants may do so seamlessly without being consciously aware that they do. When participants demonstrate through their interaction that there are differences and these are being resolved in some way, what is hoped for is that after their problem-solving session, their shared output is greater than the sum of their contributed viewpoints and that they have, as a group, reached greater convergence in whatever it is they may be trying to solve. Some factors frequently mentioned in studies of online collaborative problem solving stress communication, theories of learning, dynamics of small groups and the interplay between the activity of problem solving and the computer support which scaffolds it.

A question of communication

Online problem solving is frequently compared to face-to-face problem solving under the rubric that the mode of communication through which the problem solving takes place impacts the quality of interaction. The quality of interaction is often measured through the ease with which the interaction takes place. Media richness theory attempts to explain how the form and flow of information may impact understanding, especially through the reduction of uncertainty and equivocality (Daft & Lengel, 1986). It proposes that negotiation would be more difficult to conduct, the more impoverished the communication medium is. Consequently, face-to-face negotiation would be described as easier to conduct than computer-mediated negotiation performed through text messages. Media synchronicity theory proposes that communication effectiveness is influenced by matching the media capabilities to the needs of the fundamental communication processes called conveyance and convergence (Dennis & Valacich, 1999). It identifies a set of five media capabilities considered important to group work because these are the capabilities an online environment would require, for it to be suitable for the negotiation required for collaborative problem-solving. Since

negotiation is commonly accepted as a way by which participants in a joint activity resolve their differences, these theories offer some insight on how participants may use the unique capabilities of computer-mediated communication to make up for its assumed impoverishment in comparison to face-to-face communication.

Theories of learning

How differences are resolved is also taken up under theories of learning and the approaches to learning based on them. In the theory of learning called *social constructivism*, knowledge is seen to be socially co-constructed through negotiation before it can be internalized by children (Stahl, 2006, 182; Vygotsky, 1930/1978, 90). In the theory of *distributed cognition*, 'knowledge is co-constructed by interactions among people and their shared artifacts, including prominently by means of *negotiation* practices that result in establishing a common ground for understanding' (Stahl, 2006, 183). A theory and approach to learning such as *situated learning* views learning in terms of changing relations within the community of practice, where knowledge is negotiated interactively and through co-construction (Lave & Wenger, 1991). In distance education, negotiation brings people's ideas back together, thus making sustained, in-depth knowledge building possible (Stahl, 2006, 182).

Theories for small groups

Negotiation is also studied for its role in the dynamics of small problem-solving groups. In such groups, important differences among participants' individual representations converge in a shared representation through negotiation. Prior to negotiating a shared representation to come to a solution, teams need to detect differences in individual representation (Beers, Boshuizen, & Kirschner, 2003). Two parts in negotiation are described, a process of negotiation of meaning and a process of negotiation of position as well as a list of primitives specified: contribution, clarification, verification, acceptance/rejection and position (Beers et al., 2003).

The mutual impact of computer support and negotiation

Flexible structuring

The field of CSCL is especially interested in negotiation in collaborative learning (Stahl, Koschmann, & Suthers, 2006). The question of how computers may facilitate support for problem-solving is not only a theoretical problem but a practical one as well (Kirschner, Buckingham Shum, & Carr, 2003; Koschmann, 1996). The literature includes not only studies on how computer support may affect negotiation but also how a group engaged in negotiation may use available computer support. Systems may consciously follow particular theories in their design. For example, designs which follow the rubrics of *flexible structuring* are intended to structure interactions. *Flexible structuring* operationalizes its design approach by 1) providing a restricted set of communicative acts that can be used in the interaction, without necessarily enforcing their use in given contexts, and 2) providing flexible constraints and guidance on the use of certain communicative act sequences in specific dialogue contexts (Baker & Lund, 1997).

Negotiation and problem solving

Literature associating negotiation and problem-solving is frequently linked with the effort to find how computers may support negotiation. For example, an overview proposed by Lim and Benbasat proposes that 'the use of computer support will have much to offer in terms of compensating negotiators with what they lack in conducting rational negotiations, that is, higher information-processing capabilities and capacities' (1992, 32). Other studies discuss negotiation in the context of how groups and individuals behave in a computer-mediated collaborative work setting. Thus group activity during which negotiation takes place may be analyzed from three perspectives; namely, (i) a group's performance in reference to other groups, (ii) each member in reference to other members of the group, (iii) the group by itself. Such a study may seek to characterize group and individual behavior in a collaborative setting through a set of attributes which would enable the identification of collaborative activity which leads to negotiation towards a shared understanding (Barros & Verdejo, 2000). Related studies show how computer-mediated communication affects group negotiation. Negotiators' performances in terms of negotiation process and outcome are affected by the communication medium; face-to-face and computer-mediated communication are compared to each other (Rhee, Pirkul, Varghese, & Barhki, 1995). Studies which focus on specific communication tools such as chat, may explore the interaction between the richness of communication (Daft & Lengel, 1986; Kock, 2001, 2004, 2005) and its impact on the recipient of the communication (Spencer & Hiltz, 2003).

Computer support is thus seen to impact problem solving while problem solving determines how computer support is used.

DATA AND METHODOLOGY

A fine-grained analysis of the postings produced by the participants in the course of their online quasi-synchronous problem-solving session is essential *to describe how participants resolve their differences through the tools available to them*. The paucity of research which documents how differences are resolved in an online synchronous collaborative problem-solving session is a motivation for this exploratory study to describe resolution of differences as it is experienced and recognized by a collaborative problem-solving group.

In this paper, we will be investigating the resolution of differences in a small-group online interaction. Through a detailed analysis of an excerpt from an online chat among three middle-school students, we will develop a notion of resolution of differences as the interactive production of agreement within a small group. Participants may differ in how they approach a problem as well as the sequencing of multiple approaches which they may try. Participants may differ on how individual participants may be allowed to contribute to the unfolding of approaches, assessment of solutions. Participants may resolve their differences by changing their own as well as others' modes of participation. The analysis of how they resolve their differences in this excerpt will indicate how they accomplish their collaborative effort within the peculiarities of a quasi-synchronous collaborative mathematical problem-solving environment.

The data we present in this analysis comes from a log of a problem-solving session conducted by the Virtual Math Teams Project. This project is an NSF-funded research program that investigates the innovative use of online collaborative environments to support effective K-12 mathematics learning. The chat environment used by the participants is AIM®. The unconstrained setup of the chat environment means that the participants will not be restricted in both the format and the content of their postings.

We intend to describe how participants in a problem-solving session resolve their differences as they define, understand and solve a mathematical problem presented to them in a quasi-synchronous online environment. By using the actual log of an interaction, we seek to understand the resolution of differences, by seeing how it proceeds as experienced by the participants themselves. We use a method of analysis developed from conversation analysis. Just as conversation analysis has been used to analyze different aspects of plea bargaining (Maynard, 1984), negotiation in the workplace (Firth, 1995) as well as the discussion and assessment of a theory in a problem-based learning group (Glenn, Koschmann, & Conlee, 1999), a method based on it can be used to analyze resolution of differences in chat. At face value, chat seems similar to conversation (O'Neill & Martin, 2003; Zitzen & Stein, 2004) but is different from it (van Bruggen, Kirschner, & Jochems, 2002; Vronay, Smith, & Drucker, 1999). Chat is also distinct from conversation, because it is quasi-synchronous (Fuks, Pimentel, & José Pereira de Lucena, 2006; A. Garcia & Jacobs, 1998; A. C. Garcia & Baker Jacobs, 1999) where the output of a posting is visible but its production is not. The break between production and output disrupts the turn-taking protocol found in face-to-face conversation.

This analysis will be conducted through a description of the interaction of the participants as they conduct their mathematics problem-solving and engage in the 'members' methods for making those same activities visibly-rational-and-reportable-for-all-practical purposes, i.e., 'accountable,' as organizations of commonplace everyday activities' (Garfinkel, 1967, vii). Through this method, we describe how the chat participants put forward competing claims, recognize each other's contributions and resolve the differences they have, to reach a solution. We believe that a fine-grained analysis of their resolution of differences can further the design effort for better interfaces and affordances that would support better knowledge-building through facilitation of resolution of differences in quasi-synchronous online computer-supported collaboration.

Our research question is: *How do participants in an online quasi-synchronous collaborative mathematics problem solving resolve their differences?* Aspects of this question are: *How are resources achieved? How are choices and order of approach determined? How is the validity of an approach collaboratively assessed? How is the appropriateness of a proposed solution collaboratively assessed?*

ANALYSIS

The excerpt comes from an AIM® log of PoWwow 10. The three participants Mario, Alice and Fatima (*names anonymized*) were given the URL to the problem (Figure 1) prior to the problem-solving session. Thus, they had an opportunity to look at the problem. However, it is not known if any of them had actually solved the problem individually prior to their online problem-solving session. The participants, who had described themselves as middle-school students, were not known to each other. They were also instructed that the moderator's role is restricted to helping how to use AIM® and post whatever drawings or images the participants may produce (line 011) so that all the participants may see them.

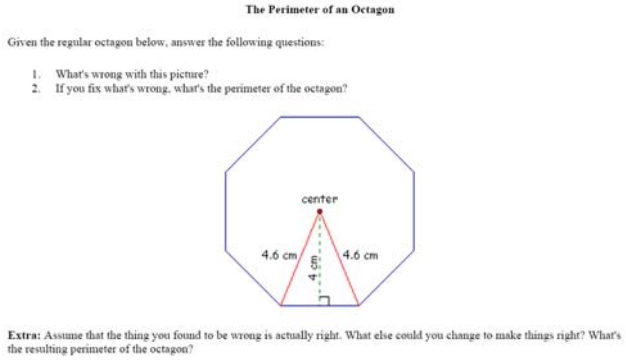

Figure 1. The Perimeter of an Octagon Problem

The excerpt which consists of lines 010 – 077, lasts about twelve minutes. It is preceded by about a minute of introductions. Though the whole session lasted about two hours and produced approximately 580 lines, not all the participants stayed throughout. In the excerpt included in the study, all the participants were present. While the session continued for about an hour and a half more after the time interval indicated in this excerpt, some participants left the session earlier.

At line 010, Alice checks if all the participants are present. The moderator posts that all the participants are present. The issue of who the participants are, is acknowledged as settled by line 013. The issue of who the participants are, is important because posts whose intended recipients are unnamed or not clearly specified in some form or other, are directed to all the participants. Knowing who are the intended recipients of a post makes it possible to determine who among the participants is or are allocated participation. Since the participants are present, a posting asking for the next step is expected; the 'so' posting in line 014 opens up a turn which will orient the participants to the next task. This task is supplied by MFPowwow, who informs the participants that they may start. We note that MFPowwow has previously self-identified as the moderator for the session, presenting herself as somebody who can provide a method by which pictures, held by participants can be shared with other participants. *Seventeen* seconds elapse before a participant tries to 'break the silence' by typing 'Ok'. The silence continues and the same participant, Alice, attempts to restart by asking if anyone has a picture. A post such as line 017, where Alice is asking whether a picture (stated as 'pic') – is available, is directed to all the participants and any of the participants can be expected to produce a response. Mario establishes the availability of the desired resource by stating where it is found, namely, in the problem statement.

010 Alice (7:01:05 PM): Is this everyone?
011 MFPowwow (7:01:15 PM): If you create a picture that you would like to share with your group, you can mail it to powwow or you can make a direct connection with me.
012 MFPowwow (7:01:24 PM): This is everyone tonight.
013 Alice (7:01:36 PM): ok
014 Alice (7:02:04 PM): so…..
015 MFPowwow (7:02:12 PM): So you've all seen the problem. If you've got any ideas, now's the time to start. :-)
016 Alice (7:02:29 PM): Ok
017 Alice (7:02:38 PM): Anyone have a pic?
018 Mario (7:02:58 PM): Just the one with the problem statement
019 Alice (7:03:17 PM): lol
020 Mario (7:03:25 PM): Should we label some points?
021 Mario (7:03:56 PM): Like, center is O
022 Alice (7:04:04 PM): We could do that
023 Mario (7:04:21 PM): Vertex where red line meets is, what, V?
024 Alice (7:04:38 PM): The center?
025 Mario (7:04:47 PM): No, down at the vertex
026 Alice (7:04:52 PM): oh
027 Alice (7:05:00 PM): That might help

The visibility of the indicated resource makes it possible for the participants to now make proposals regarding how the problem solving can be approached. Mario proposes labeling some points at lines 020 and 023, putting examples of how labeling can be done. The questions of lines 020, 023 and 024 attempt to coordinate where the participants ought to be orienting themselves in the problem-solving process by pointing to words in the problem formulation. They also introduce labels as new resources which can be used for a common approach to the problem. For example, both Mario and Alice use the term 'center' which can be found in the diagram (Figure 2), confirming their use of the same resource.

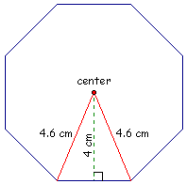

Figure 2. The diagram prior to 'labeling' by participants

The questions also propose candidate answers which display what the appropriate answers to the question should be. Supplying a candidate answer enables the person raising the question to show what an acceptable answer can be (Pomerantz, 1988). In this case, supplying candidate answers enables Mario to make Alice participate in labeling. It also enables Alice to get Mario to participate in the approach she starts when she asks 'Anyone have a pic?' in line 017. Through the use of candidate answers, participants are able to agree that the diagram is a resource that will be used in the problem solving. That they agree that the diagram is a common resource means that it would not be surprising for the participants to continue whatever approach they may be using in their problem solving. This however, does not immediately take place since Alice proposes finding out what's wrong with the picture *first* instead of labeling, in line 028. Her proposal is not taken up in the succeeding postings, since Mario continues with the labeling and even has Alice participating in it in lines 029 and 030.

After participating in the labeling, Alice adds a claim to her proposal in offering a possible resource for the proposal that she is making. The offer, made in line 031, creates an opportunity for the other participants to ask for an elaboration of the idea. Their asking would constitute an uptake of her proposal. Line 031 continues an attempt to convince the other participants to use her approach first, as proposed in line 028. But this is again not taken up as Mario proposes to use the Pythagorean Theorem together with the labels B and V to find what BV is. Alice now unequivocally opposes Mario's approach by posting line 033.

Bringing the Pythagorean Theorem is made possible by the prior labeling of the vertices BV. While it is Alice who first brings up the possibility of using a picture as a resource through line 017, it is Mario who initiates its labeling. By line 30 three points are labeled and all the labeling is considered complete, inasmuch as no other labels are made during the rest of the session. By line 033, it is established that the participants are using a labeled diagram (Figure 3) as a common resource.

The rejection stance of Alice in line 033 opens up a possible range of responses. The stance can be ignored, it can also be rejected outright or it may be taken up. The latter may lead to a reorientation of the group to Alice's approach in place of wherever the group may be. Line 034 signals an uptake: asking Alice to state her position and opening a turn which invites the other participants to a new orientation toward Alice's proposal. Mario's posting at line 034 comes across as a response to Alice's line 031. Mario interrupts his own presentation to seemingly favor an uptake of Alice's idea, which is yet unstated. Alice takes the turn in line 035, repeats earlier claims made at lines 028 and 031, paraphrases the wording of the problem and uses, in line 036, the same label 'BV' used by Mario in line 032. By referring to its wording, she positions herself as representing the problem designer and claiming what the problem designer would accept as a valid approach for solving the problem. She now states that what Mario proposes to find cannot be found based on what was said in the problem. The word 'so' connects her present claim about the futility of finding BV to the authority of what was stated in the formulation of the problem.

028 Alice (7:05:16 PM): Lets find out whats wrong with the pic first.
029 Mario (7:05:20 PM): You name where the green line meets the base
030 Alice (7:05:30 PM): B
031 Alice (7:06:19 PM): I have an idea that might help us find whats wrong with the pic.
032 Mario (7:06:30 PM): We could use good ol' Pythag thm to see what BV is
033 Alice (7:06:40 PM): Lets not
034 Mario (7:06:46 PM): What's your idea?

035 Alice (7:07:01 PM): It states that something is wrong with the pic.
036 Alice (7:07:08 PM): so we can't find what BV is
037 Mario (7:07:31 PM): Yeah, and I think if we 'found' BV, it would be something not possible

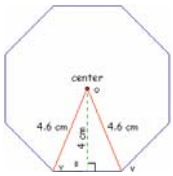

Figure 3. A labeled diagram

Lines 035 and 036 are expressed as Extreme Case formulations, where not finding BV is linked with the problem statement that something is 'wrong with this picture' (Figure 1) and where not finding BV is proposed as a phenomenon 'in the object or objective rather than a product of the interaction or the circumstances' (Pomerantz, 1986, p. 220). Furthermore, Alice uses the inclusive word 'we', softening a dispreferred criticism of what Mario is trying to do. The linking of the claim about BV to the wording of the problem also makes it possible for her to disagree with Mario without directly claiming that the latter is mistaken in proposing to look for BV. At line 037 Mario agrees with Alice's claim while posing a hypothetical "if we 'found' BV" statement that if BV were ever found, its value would be 'something not possible', later explained as a BV whose dimension does not fit with what is known about the problem.

Mario's claim in line 037 is further elaborated in lines 038 - 039, 042, 044 – 046, concluding with a proposed answer at line 071 that the octagon (Figure 4) is really a hexagon (Figure 5). Mario continues his approach and at line 071 points out a possible wrong thing, that the dimensions of the octagon (Figure 4) are really approximations of a hexagon (Figure 5). In showing the consequence of the computation of BV, Mario demonstrates that the value of BV results in a hexagon instead of an octagon and displays a finding which is incompatible with what is known about the problem. He uses a method of mathematical proving called *reductio ad absurdum* or proof by contradiction.

Mario's reasoning is based on the labeled dimensions of the diagram while Alice's reasoning is based on the problem statement that there is something wrong with the picture. By implication, its listed dimensions may not be correct, thus supporting her later claim that the diagonal is not 4.6. This seeming conflict between the competing approaches to the formulation is resolved when Mario accepts her claim by posting 'Right' at line 067 and continuing his presentation by posting line 069 which incorporates her 'diagonal is not 4.6' and his result '4.54 ish' in the post 'Otherwise, the red lines and the base are almost an equilateral triangle'. The acceptance of line 069 is designed to lead to the acceptance of line 071. After Alice posts 'No' at line 072; Mario withdraws his suggestion about the inaccuracy of the shape of the figure through lines 073 and 075 where he explicitly announces an invitation to all the participants to 'stick with octagon' that is, assume that the figure has the correct shape. This is then followed by line 076 where he asks the participants to assume that '4 is right'. Alice's claim that *the diagonal is not 4.6*, is thus accepted, as that claim cannot be simultaneously true if 4 is assumed to be right.

038 Mario (7:08:10 PM): 16 + BV^2 = 21.16
039 Mario (7:08:20 PM): BV^2 = 5.16
040 Alice (7:08:23 PM): I got it
041 Alice (7:08:29 PM): I know whats wrong with the pic
042 Mario (7:08:31 PM): BV = 2.27
043 Fatima (7:08:44 PM): ok. now i'm following!
044 Mario (7:08:47 PM): That makes the base about the same as the radius
045 Mario (7:09:01 PM): That can't be
Alice has left the chat room. (This is a system message.)
046 Mario (7:09:19 PM): Central angle would be about 60 deg, that way

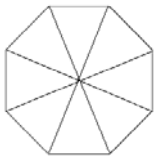

Figure 4. Octagon. Each of the eight angles at the center of a regular octagon is 45º = 360º/8.

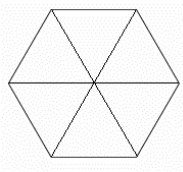

Figure 5. Hexagon. Each of the internal angles of the 6 triangles of a regular hexagon is 60º.

While Mario's postings build up to the claim that the octagon may really be a hexagon, Alice repeats her claims about knowing what is wrong with the picture (lines 060 and 062) and offers the claim that the diagonal is not 4.6 (lines 066). The claim is accepted by Mario in lines 067 and 069, and is linked with his own posting that the base would be '4.54 ish' (lines 063 and 065). Line 069 is used to build up a claim that given the computed values of 4.54 and the labeled given value of 4.6 for the 'red lines' the triangle formed is equilateral. He then builds on this a proposal for an answer, that the figure described by the problem is a hexagon rather an octagon.

Interspersed with the discussion is Mario's attempt (line 055) to check Alice's coordination with the rest of the problem-solving process after she reentered the system after a connection loss (lines 049 – 050). This check makes it possible to expect Alice to ask for the value of BV, even though that value had already been supplied by Mario at line 042. This gives Mario an opportunity to restate the basis for the computation of BV even though he had already said previously that the BV would be an impossible value (lines 044 – 046).

047 Fatima (7:09:30 PM): yes
048 Fatima (7:09:35 PM): i see
Alice has entered the chat room. (This is a system message.)
049 Alice (7:10:05 PM): Sorry
050 Alice (7:10:10 PM): Lost connection
051 Fatima (7:10:13 PM): what happened?
052 Fatima (7:10:15 PM): oh
053 Fatima (7:10:26 PM): why does that happen so often?
054 Fatima (7:10:31 PM): nvm
055 Mario (7:10:43 PM): Do you have what's done so far
056 Alice (7:10:51 PM): What did you say BV was?
057 Fatima (7:11:05 PM): 2.27
058 Mario (7:11:10 PM): With the numbers given, BV would be
059 Mario (7:11:11 PM): yeah
060 Alice (7:11:14 PM): I think thats wrong
061 Fatima (7:11:19 PM): how so?
062 Alice (7:11:28 PM): I know whats wrong with the pic
063 Mario (7:11:31 PM): base would be twice that
064 Fatima (7:11:33 PM): what
065 Mario (7:11:41 PM): 4.54 ish
066 Alice (7:11:45 PM): The diagnol is not 4.6
067 Mario (7:11:51 PM): Right
068 Fatima (7:12:02 PM): exactly
069 Mario (7:12:14 PM): Otherwise, the red lines and the base are almost an equilateral triangle
070 Alice (7:12:32 PM): I think this requires trig
071 Mario (7:12:50 PM): So, one possible wrong thing is, this is really a hexagon
072 Alice (7:12:56 PM): No
073 Mario (7:13:01 PM): Right

074 Alice (7:13:09 PM): Im talking about the triangle diagnol
075 Mario (7:13:11 PM): Let'sd stick with octagon
076 Mario (7:13:24 PM): So we assume 4 is right
077 Alice (7:13:32 PM): yes

Line 074 is an explanation attached to the 'No' in line 72 and is an elaboration of Alice's line 070 posting about a possible use of trigonometry for the diagonal. Since Alice has claimed that '*The diagnol (diagonal) is not 4.*6' line 070 may be actually be a suggestion to use trigonometry to compute the true length of the diagonal. This is another method to find a value for BV since ∠BOV = 22.5º can be inferred from the problem's definition.[1] Another approach could have been started. However, Mario does not use Alice's self-repair in 074. But by taking up only the first part (line 072) of a two-part post (lines 072 and 074), as he does here, he is able to include the part of Alice's assertion, which can be taken as a rejection of line 071, and state an invitation to produce an approach worded in a form acceptable to her. Mario's new proposal 'to stick with octagon' and 'assume 4 is right' at lines 75 and 76 meets with Alice's 'yes' at line 077, a token of agreement. The rest of the log after line 077 then shows the participants using the same approach to solve the other parts of the problem, confirming their agreement regarding both approach and participation in solving the rest of the problem after this contentious phase which becomes clearly visible in line 028, even though it may have begun as early as line 022.

DISCUSSION

Though this session was designed to be a collaborative problem-solving session and the given problem was designed to facilitate discussion. The problem can admit several possible answers.[2] Since this is so, participants who are predisposed to look for a single answer may find their projected answer different from the projected answers of other participants. Similarly, those who conceive only a single approach may, in this session, find themselves having to justify their approach against contrary or opposing claims.

However, it is not possible to assume that the participants are acting collaboratively. Their interaction needs to be examined for phenomena which show that they are not only acting collaboratively but recognize that they are doing so. More specifically, their interaction needs to be examined for methods which show how they resolve their differences in the conduct of their problem solving. This requires looking at sections of the excerpt where participants seem to be reasoning, arguing and engaging in interactional activity which suggest that they are resolving their differences.

Overall, we observe that participants create a participation framework. A participation framework articulates how the participants locally manage their interaction. This framework includes the work they do to resolve their differences. We observe that the participants manage their participation in the following areas:

- The achievement of resources
- Choice and order of approach in defining the problem
- Assessment of validity of an approach
- The appropriateness of a proposed solution

While these areas overlap in the complexity of the interaction that takes place, we highlight each of them for the sake of analytical clarity.

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[1] Since the triangle is formed by the two 'diagonals' and the base (a side of the octagon), its vertex at the center O would have been $360^\circ/8 = 45^\circ$. The ∠BOV, being half of 45º, would be 22.5º. The value of the diagonal can be found by finding the cosine of 22.5º. Using this method, the diagonal would be ≈ 4.33.

[2] Some possible answers are:

1. 4.0 cm is wrong.
2. 4.6 cm is wrong.
3. Both 4.0 cm and 4.6 cm are correct but the 'center' is not at the center of the figure.

(Math Forum Geometry Problem of the Week archive posted April 6, 2004)

The achievement of resources

Labels and their use

Among the resources used in the problem solving is the diagram included in the problem formulation. While the picture, as part of the problem formulation is a resource made available for the problem solving, the ways in which it will be used in the conduct of the problem solving is yet to be articulated in the task of problem solving. It becomes a topic of discussion as the participants focus on the picture that they are going to use and how that picture is going to be manipulated. We find Alice asking for a picture and Mario offering the picture included in the problem statement. *That Alice asks for a picture from the participants reveals that she does not assume that the picture which will be used in the problem solving is not necessarily the diagram made available in the problem formulation.*

Mario proposes labeling the picture; the labels become new resources, which are introduced as they are used in subsequent postings. The chat participants use them in combinations to frame their discussions. For example, Mario proposes that the Pythagorean Theorem can be used to compute the length of BV (line 032). The designation of the length BV is only possible because in previous postings, the labels V and B were attached to the vertices by Mario (line 023) and Alice (line 030) respectively. Through the labels, participants are able to specify – with greater granularity -- which parts (initially with predefined values and later including the participant-supplied labels) of the diagram, are being referred to.

We note that this labeling is not achieved without some resistance from another participant. Nonetheless the labels are used by the participants in their subsequent discussion. Prior to the labeling of B, Alice had interposed an objection by proposing 'to find out whats wrong with the pic first' (line 028). This resistance does not stop Mario from inviting Alice to label a new vertex 'B' (for we note that the 4-second interval between lines 028 and 029 is too short for Mario to have started typing line 029 after 028 had been posted). Alice's resistance does not stop her from contributing a label herself (line 030)! The resource achieved is a labeled diagram (Figure 3), though the drawing itself is never shared as a visible artifact among the participants. Indexical symmetry (Hanks, 1992) is achieved, as manifested in the shared use of the labels 'attached' to the original diagram in the problem formulation.

Though the participants did not readily agree on labeling, they all used the labels once they had been placed. These differences regarding placement are resolved by participants when they allow and assist each other in the creation of resources even though as individual participants they may not agree with the need to create these resources. One example of this assistance appears in line 024 when Alice's question disambiguates where of three possible positions a new label is supposed to be. It is also notable that though there are two red lines which meet the criteria 'down at the vertex', the participants do not show any need to label both vertices to differentiate them from each other. When the whole excerpt (lines 010 – 077) is examined, references to a triangle formed by the vertices O, B and V do not specify which of the two triangles is being pointed to. However when claims about the consequences of this labeling are made later (lines 044 – 046 and 069), the references use the two triangles which can both be classified as OBV triangles (Figure 3).

The labeling and use of the diagram is thus an interactional achievement. While the initiative for labeling is pushed forward by Mario, the participation of the other participants is critical for its acceptance even though that acceptance may be a grudging one. Its use as a shared resource for framing an approach to the problem is an interactional achievement since the use of labels requires their acceptance by the group that the labels as resources for group interaction for problem solving. This acceptance is displayed in their use of the labels.

The attainment of agreement regarding what are acceptable to the group as common resources does not mean an end to their continuing differences and subsequent attempts to resolve them. The same resources may be used later to produce a new proposal to oppose what is being presented as a consequence of the agreement on shared resources. The outright rejection of Mario's suggestion to use the Pythagorean Theorem is such an example; its position characterizes it as Alice's defensive stance. But Mario addresses the objection and continues his approach. It is noteworthy that Alice's rejection of Mario's proposal is not based on what has been agreed about in previous postings; she bases her argument on the problem statement 'It states that something is wrong with the pic.'

The interactional achievement in labeling also makes possible the emergence of incompatible approaches. Mario builds his argument by using the labels to invoke the appropriateness of the Pythagorean Theorem as a tool for the problem at hand. Once labels V, B and O had been placed, the value of BV can be computed. Mario does not even have to define which of either triangle he is using. Once he was able to compute BV, he doubles its value and highlights an isosceles triangle whose base is made up of the two possible BV's. The value of the double BV is then compared against the red lines.

Colors and shapes

Participants use labels such as B, O and V in their interaction, but they also use other resources such as color, shapes and terms in the problem solving. For example, lines 066 and 074 use the term 'diagnol' (diagonal), line 069 the terms 'red lines' and 'base', line 070 uses 'trig' (trigonometry) though these words are not used in the actual formulation of the problem. These words are used by the participants to resolve their differences regarding the question of whether the diagram is an octagon (Figure 4) as formulated or a hexagon (Figure 5) misrepresented as an octagon (line 071). Words such as 'red lines' and 'base' are used to describe and constitute mathematical shapes such as 'equilateral triangle', hexagon and octagon; the labels B, O and V are not used at all.

We thus make the general observation that resources, whether participant-produced such as labels, or included in the problem formulation, are *situational*. They are situational because they are brought into the problem solving. Their use as resources is contingent on their use as resources in the concrete situation of problem solving. Participants 'bring them in' as resources, using them as they see fit and appropriate for problem solving. Thus while the labels OV can have been used in place of the term 'red lines' or the diagonal and VV for base, they are not. By using 'red lines' and 'base', the participants are able to constitute an 'equilateral triangle' which would have been otherwise constituted from the two right triangles formed by the lines formed by various combinations of the labels B, O and V. By using 'red lines' and 'base' the participants need only the diagram which had been included in the problem formulation and do not need to assume that the other participants have a diagram labeled with B, O and V.

Choice of approach

Two approaches are presented by the two of the three participants. One approach is seen to evolve into a use of the Pythagorean Theorem; the other builds its argument on the formulation that something is wrong with the picture. We also note that the participants attempt to resolve not only the approach but also the order in which they are used to engage in problem solving. As proposed by participants, an approach may be described in a general way by a participant or it may be named after its initial steps have been presented. In the former, an approach is seen as something to be made more explicit in future postings while in the latter, an approach is proposed after some of its steps have been executed. An example of the former takes place when Alice proposes to find out what is wrong with the picture *first* (line 028). An example of the latter is shown in line 032 when Mario suggests the Pythagorean Theorem to compute for BV after the diagram had been labeled by the participants.

The two different ways through which Alice and Mario approach the problem solving are now visible. While Mario uses labeling and builds up an argument to use the Pythagorean Theorem, Alice uses the wording of the problem to argue the opposite. However, they both use the labels in orienting the participants in the problem-solving session. They both use labels in their negotiating activity. An example of this takes place when Mario, in line 037, agrees with the claim of Alice by modifying his claim about BV. In response to Alice's posting that "we can't find what BV is", Mario posts "Yeah, and I think if we 'found' BV, it would be something not possible." While his use of 'I' qualifies his subsequent claim as an opinion, the claim opens up another way to approach the problem, which is to show that a computation of BV would result in a finding which is incompatible with known parts of the problem. Mario's post thus makes it possible for the participants not to have to choose one among the competing approaches exclusively. Alice's claim is accepted but Mario continues using his approach. He computes for BV and then makes a claim about the picture using the term 'central angle' in line 046.

The two approaches require different work from the participants. After an approach is described in a general way, its proponent follows up how it can be implemented. Thus, we find Alice claiming in line 031 that she has an idea to find what is wrong with the picture. For the other approach, however, the justification for the proposed approach is sought in the steps already taken to show that the proposed approach is fruitful. Thus, in line 032 Mario proposes that the Pythagorean Theorem can be used to compute BV after labels had been affixed to specific vertices, labels which then make it possible to specify which parts of the diagram are being referred to.

We note that while Alice's approach is proposed as early as 028, it is only taken up in line 034 and only after she has directly contradicted Mario's proposed approach. The contradiction is highlighted by her use of 'BV' as the centerpiece of her objection, by claiming that it cannot be found. Mario accepts the objection and builds on it by proposing that if BV can ever be found it would be an 'impossible' value but he then computes it. After finding its value, he makes a series of additional claims to demonstrate that the value obtained would be incompatible with what is already known about the problem. While it is not possible to know in advance what Mario knows about BV, his proposal to use the Pythagorean Theorem suggests an expectation, on his part, that BV would not be an acceptable value. The value should be consistent with the values given in the diagram, but it does not, confirming what was predicted in line 037.

When the approaches are compared side by side, we find that central to Alice's approach is that if there is something wrong with the picture then nothing can be found using the picture as it is presented. Adding labels would not help. If the picture is wrong, an approach using it would also be wrong. Mario's approach takes the position that the Pythagorean Theorem can use labels to produce a result that would eventually show that the picture as presented is wrong. The approach of Mario consists in converting the problem to something more familiar, which he describes as "good ol' Pythag thm" (good old Pythagorean Theorem). By describing the Pythagorean Theorem as '*good ol'* (good old)', Mario calls the attention of the participants to a consideration that the Pythagorean Theorem is an established method that they are familiar with.

Participants use the pronominal 'we' and its other forms, showing attempts to invite the other participants to use a particular approach. The difference between the two approaches initially surface in the disagreement regarding the use of the picture. Participants are invited to defer or postpone the use of other approaches. While the participants do not clearly give up their respective approaches, they resolve the question of which approach to use by giving way to each other or by not interposing objections as another approach is being laid out. An example of giving way shows in line 037 when Mario reconciles Alice's approach with his own since the BV which Alice claims to be impossible to find, is described by Mario as an impossible value. Mario thus incorporates Alice's claim into his own approach, though he continues to compute for BV!

Alice	Mario
017 Anyone have a pic	
	020 Should we label some points? 021 Like, center is O
028 Lets find out whats wrong with the pic first 031 I have an idea that might help us find whats wrong with the piic	
	032 We could use good ol' Pythag thm to see what BV is
033 Lets not	
	034 What's your idea?
035 It states that something is wrong with the pic. 036 so we can't find what BV is	
	037 Yeah, and I think if we 'found' BV, it would be something not possible.

The issue of who gets to present an approach is also resolved by participants. In chat, participants may contribute whenever they want to post. Participants may keep on posting without paying attention to other participants. In this case, however, participants exhibit that they are monitoring each other's participation and regulate their own postings in reaction to other participants. This is the case in line 034 where Mario stops his presentation of his approach after Alice's claim in line 031 and her open opposition in line 033. It does not seem accidental that Mario stops here because there is a claim that would potentially move a proposed approach forward. Alice's suggestion in 028 does not present a way to show how it can be operationalized. In claiming to have an idea to find what is wrong with the picture, Alice offers a doable step which can be used in her approach. Mario gives way by downgrading his approach through the use of the 'I think' hedge instead of the assertions used in earlier postings such as in line 032.

The type of participation in the problem solving is also negotiated. In the process of agreeing that the diagram is a common resource, there is negotiation regarding how the diagram is to be used in the problem solving. The negotiation in participation includes agreeing in what order several approaches may be used. Thus in line 028, Alice proposes finding out what is wrong with the picture first. This proposal, if taken up, would expect Mario to stop labeling. However, Mario, instead of stopping, asks Alice to label a point.

In summary, we note that in choosing an approach among several proposed and the order in which they are used, the participants manage themselves as a collective instead of subdividing the problem among themselves and later coordinating the separate parts to form one solution. The participants attempt to solicit the participation of the others in whatever approach they are proposing. When the participation is not forthcoming, participants include portions of the competing approaches thus resolving in an artful way, the differences resulting from the variety of approaches being proposed. Resolution is achieved through accommodation to an alternative approach. By interacting in this fashion, the problem is constituted as a shared problem in the identification of resources, approaches and solutions.

Assessment of the validity of an approach

In the excerpts analyzed above, participants make their claims regarding the validity of their respective proposed approaches through different ways. A participant may appeal to the problem formulation, thus invoking the authority of the writer of the problem. Thus we find Alice making repeated references (lines 28, 35, 41) to the formulation of the problem which states that something is wrong with the picture. By insisting on the formulation, Alice assesses that a method which is based on labels and information from the picture would fail (line 036). A participant may also appeal to the use of a familiar method. Thus Mario builds an approach (lines 020 – 032) which frames the problem as one which can be solved using the Pythagorean Theorem (line 032). Appealing to the use of a familiar method enables a participant to solicit participation from other participants who are presumed to be familiar with the method and can thus contribute to its use. Alice also appeals to a familiar method in proposing the use of trigonometry in line 070. In this case, the proposal to use trigonometry evokes a response in Mario to make an assumption (line 076) which she is willing to accept (line 077).

Assessment of the appropriateness of a proposed solution

In addition to assessing the validity of proposed approaches, participants also assess the appropriateness of proposed solutions. The appropriateness of a proposed solution is seen as contingent on how the problem is framed or defined by the participants. Mario's proposed solution is that the diagram may be that of a hexagon instead of an octagon (071). The solution is premised on the use of the initial measures given in the program. Based on these initial numbers, Mario computes values which show that the initial values lead to a hexagon rather than an octagon. The appropriateness of the solution is thus based on an assumption that the initial values may be used to produce values which are not consistent with the initial values. On the other hand, Alice bases her assessment of Mario's solution on the problem formulation which asks "What's wrong with the picture?" and is critical of any solution which uses the values in the diagram (lines 035 – 036, 060, 062 and 066). Alice's proposed solution thus starts with the claim that 4.6, which she terms the 'diagnol' (diagonal) is not 4.6 (line 066). Mario sets aside his proposed solution, accepts Alice's assumption and the group proceeds with the problem solving. The collaborative assessment of the solution is based on mutual agreement. The assumption that 4.6 is not really 4.6 is not a result that either proposed solution obtained, but the group moves on nonetheless.

Member Methods for Resolving Differences

Participants attempt to resolve their differences when there are competing proposals which show up in the interaction of problem solving. As proposals are advanced, they may be accepted, rejected or ignored. Acceptance is shown in an uptake of the resources offered by the proponent of the accepted proposal. The use of the resources thus taken up appears in the interaction as resources used in similar or compatible ways by the participants who have accepted the proposal. Acceptance thus means that the participants build on each other's postings and co-construct their framing of the problem, crafting their solution or assessing the adequacy of their proffered solution. In the face of rejection, participants may adopt other strategies to change the allocation of participation. The spurned proponent may recycle the proposal or post an alternate message which claims to have some idea which would shed light on the group activity. However, this alternate message would require the other participants to ask the rejected proponent to reveal the idea. If this ploy works, then a counter-proposal may arise and begin another cycle of exchanges. If a proposal is ignored, its proponent may decide to go along with the other proposal, or present a new proposal, or lurk.

While these member methods may not appear different from how differences are resolved in a face-to-face setting, there is a difference in how these methods unfold in a quasi-synchronous setting. Since acceptance, rejection or indifference are communicated through postings, whose production cannot be monitored but read only in their final form, acceptance, rejection or indifference may not appear immediately after the proposals to which they would be paired, if the interaction were face-to-face. This makes it possible for participants who would otherwise be in an impasse to select parts of a long series of related postings which they can append to their own postings to break an impasse and thus produce agreement. Thus we find Mario appropriating the postings of Alice and including them in his own presentation. Similarly, we find Alice using the labels instigated by Mario in making her own contrary claims regarding the reliability of labels. We note that after these appropriations, the interaction continues to another issue.

Participants may make their agreement visible when they post tokens of agreement in reaction to other participant's postings whose previous parts are made to fit a competing approach. Prior to these tokens of agreement, participants show that they are aware that there is some problem, that a solution has to be found, that the solution has to be implemented, and that there are misalignments according to how any one of the three is assessed, understood or taken into account by other participants in the interaction.

The awareness of some problem is expressed in postings which supply additional resources to help frame the problem. For Mario, these additional resources are in the form of labels which eventually frame the problem as a type which can be solved using the Pythagorean Theorem. For Alice, labeling is not as consequential since there is something wrong with the picture and by implication, the predefined labels are suspect. Mario proposes a solution which is based on the application of the Pythagorean Theorem while Alice proposes a solution which ultimately assumes that one of the labels is not correct and she chooses that the diagonal is not 4.6. Mario, in proposing the Pythagorean Theorem, puts forward an approach that the participants are assumed to be familiar with, while Alice proposes her approach based on the problem-designer's formulation that there is something wrong with the picture.

We also note that the participants try to negotiate the order in which varying approaches may be applied to the problem at hand. Both Mario and Alice try to get the other participants to apply their approaches first. Both of them do not criticize each other's approaches and work independently of each other until such a time when either uses some resource produced by the other to advance her own approach. Thus, Alice uses the labeling 'BV' which Mario first used to point out how the latter cannot produce a correct result from the latter's approach. Mario, in return, uses this claim to proceed to a computation of BV which then produces a result, which is not directly traceable to the use of the Pythagorean Theorem but rather to a set of properties associated with equilateral (and consequently, equiangular) triangles.

Taking then these two situations of interaction namely, the negotiation to agree on the approach and the negotiation to agree on the order in which the different approaches are applied, we find that both negotiations fail because no agreement is reached on either a common approach or the order in which they can be tried. In spite of these, the participants agree that finding BV is either impossible or even if it were found, its value would be 'something not possible'. There is agreement on a result which can be found using either proposal though neither proposal is wholly used by the whole group. The interaction is then able to continue on the basis of the point thus agreed on. The participants in this interaction simply append each other's findings to each other's approaches to come to an agreement. The agreement is confirmed by the absence of any complaint against this mutual incorporation and appropriation of each other's findings. Agreement in the latter comes without tokens of agreement though they start building on the postings of other participants. Agreement is seen as an accomplished fact which may be appreciated by the participants only after they have moved on to another topic and have seemingly simply set aside their differences without any explicit attempt to reconcile them.

To summarize then our findings regarding or research question, "*How do participants in an online quasi-synchronous collaborative mathematics problem solving resolve their differences?*", we present our findings regarding the sub-questions, "*How are resources achieved?*", "*How are choices and order of approach determined?*", "*How is the validity of an approach collaboratively assessed?*" and "*How is the appropriateness of a proposed solution collaboratively assessed?*"

How are resources achieved? Resources are *situational*, that is, they have to be brought into the problem solving. For resources to be brought into the problem solving, they need to be *achieved* and *shared*. *Achieved and shared resources* make it possible for participants to build *competing* proposals. The use of achieved and shared resources to build competing proposals shows that participants resolve their differences regarding resources which can be used for problem solving.

How are choices and order of approach determined? In choosing an approach or the order in which several approaches may be tried, participants manage their participation as a collective which works *together* rather than *subdivides* its task among its members. The problem is thus constituted as a *shared* problem. Working together means that a proponent of a proposal tries to solicit participation from other participants to use the advanced proposal. This is done through the use of the pronominal 'we' and its variant forms. Solicitation of participation may consist in prescribing a task for another participant or determining the availability of another participant for some-yet-undescribed task. Solicitation may also consist in the revelation of some strategy for problem solving, such as through the presentation of some steps which project the strategy or building on the formulation of the problem.

Where there are competing proposals and some proposals are not taken up, participants whose proposals are not taken up engage in artful ways to reallocate participation. *Spurned* proponents may recycle a proposal or present a new step which reorients participants to the *previously-spurned* proposal. In the face of competing proposals, participants may resolve their differences through tokens of agreement to an evolving proposal. Participants may also accommodate parts of a competing proposal to their own proposals. This accommodation is facilitated by the quasi-synchronous nature of chat which permits participants to use portions of multiple-line postings without necessarily using the appropriated portion as an integral part of a multi-line posting. This appropriation is permitted

by the original poster, as evidenced by the lack of resistance to the reuse of the posting for something which may even be contrary to the rest of the posting.

How is the validity of an approach collaboratively assessed? Participants may appeal to the problem formulation (and thus the writer of the problem) to claim that a particular problem-solving approach is valid. Participants may also suggest that a particular approach is valid because it uses a *familiar* method. The appeal to familiar method is used to solicit participation inasmuch as a familiar method makes it more likely that more participants in the collective can contribute to the problem solving. Participants may resolve their differences by giving way to each other without arguing against each other.

How is the appropriateness of a proposed solution collaboratively assessed? In this case study, the assessment of a proposed solution is based on *mutual agreement*. The participants agree on a common assumption. Their agreement is based on a result which *neither* proposal obtained, but they move on nonetheless.

NEXT STEPS

This exploratory study has looked at the resolution of differences in a quasi-synchronous online collaborative problem-solving environment whose only feature is a chat window. Other environments such as VMTChat offer not only a chat window but a shared graphical space as well. Just as a fine-grained analysis reveals methods through which online participants do mathematical problem solving in a text-only quasi-synchronous online environment, similar methods may be used to examine resolution of differences in quasi-synchronous online environments with dual interaction spaces, where one space uses graphics and the other, text.

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