Designing an Online Service for a Math Community

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Abstract. In the Virtual Math Teams project an online service for groups of people to discuss and collaboratively solve mathematical problems is being developed. The paper takes a qualitative approach to looking at the design-based research process of developing the platform for a synchronous math problem solving environment. We sketch the transition from early experiments with commercially available tools to a series of studies conducted with a research tool finally to the design of a platform which provides the technical basis to a scalable public service. For this design we had to take into account requirements from students, tutors, the service provider as well as researchers from various disciplines. We discuss some design decisions which lead to a platform which addresses the diverse requirements of the various stakeholders. The paper underscores the value of a design-based research process and a self-reflexive process as we develop insights about online math problem solving.

Enabling and Supporting an Online Math Community

So much math done by students is done at the individual level. Even when students work on math problems together they are often doing the work individually. The goal of the Virtual Math Teams (VMT) project is to provide an online service, as part of The Math Forum's regular suite of interactive math education services, that would allow students the opportunity to work together collaboratively in a synchronous environment in order to talk about math and solve math problems. The idea of the VMT project is to bring together students, teachers, designers and researchers all in a collaborative way to help design, develop, test, and use an online collaborative math chat service.

The ultimate goal of the VMT project is to create a self-sustaining system that would allow individuals to join a chat, become part of a well-working group, and make progress together toward increasing their math knowledge and problem solving skills. But this ultimate goal raises several important challenges. First, are there specific dynamics of a good online group. There is some conflicting literature regarding the work of collaborative groups that is unclear about whether similar ability groups work best together or if mixed ability groups work best (Ireson and Hallam, 2001). Also, should there be specific roles in the group of online problem solves and should those roles be arbitrarily pre-assigned to students or should the system pick people with different characteristics to assign them to a group together. Perhaps the most challenging issue is how to support a group as they attempt to make progress in problem solving and what to do if the group gets stuck at some point in their problem solving activities.

Theoretical Considerations

The VMT project has taken a design-based research perspective (Stahl et al., 2006, The Design-Based Research Collective, 2003; Hoadley 2002). As Stahl et al. (2006) describe, the project involves the iterative development of the online synchronous math chat service. That iterative design process involves a number of collaborators: research team, students, and math teachers. Here we will discuss the role of the research team a bit and talk more about the students and the teachers later in the paper. The research team is collaborative group of researchers from a number of different fields and math educators who meet weekly to develop and discuss the evolution of the online synchronous math chat system. The research team has done everything from collaboratively designing services to working on the analysis of data from a number of different perspectives. The research group also includes a number of off-campus collaborators who follow the research progress of the team and some of whom become on-site visiting researchers for periods of time.

For the purposes of this paper we are taking a more ethnographic perspective to talk about the overall design development process in the research team. Barab et al (2004:254) define critical design ethnography as "…a process that sits at the intersection of participatory action research, critical ethnography, and socially responsive instructional design." From their perspective their goal was to effect social change through a process of being immersed in a community and at the same time providing for that community educational design work that was developed in collaboration with the community. Porpora (1999) has suggested that action research is the highest stage of service learning because it is a form of educational opportunity where students learn from real life service opportunities in living communities, a truly inquiry and experience based process. Reason (2004:270) makes some similar points reflecting Barab et al. (2004). He suggests that action research is at the intersection of "knowledge in practice" and "participation and democracy". Barab et al. are describing a kind of parallel process to both Porpora and Reason where the immersion of the design team in the life of the community enriches the work of both groups.

The VMT is not a critical design ethnography project. However it shares several features of that work and involves an ethnographic component to the self-reflection that the research group engages in. The work in the VMT is a highly collaborative and reflective process. The research team works through all design issues and research issues together as they think about what effects changes in the chat environments are having on student participants. They also think about the nature of the math problems and which problems are best suited to collaborative online work as well as the nature of the mathematical conversations the students are having in the chats. The research team also has engaged in problem solving themselves in the chats as they attempt to get a feel for the experience of the participants in math chats. Finally the research team has involved students in the process encouraging them to tell us about what worked in the chats and what they would like to see changed in future versions of the chats. Recently we have also begun to work with a group of teachers on the project as well.

The current paper attempts to take an ethnographic perspective in that it is a large overview of the development of the chat environment and it critically reflects on the progress that we have made so far and the challenges we face. As such the data for the current paper comes from the notes that we have taken on our own process as we have in part become the subjects of our own analysis.

First Phase: Experimenting with Diverse Tools

In our design-based research at the Virtual Math Teams project (Stahl *et al.*, 2005), we started by conducting chats in a variety of commercially available environments: AOL Instant Messenger (AOL IM), Babylon, Blackboard, WebCT. Most of the early work concentrated on the use of AOL Instant Messenger for a set of math chats that we called PoW-wows after the Math Forum's Problem of the Week (PoW) on which the chats were based. The choice of AOL IM was a simple one, it was a piece of technology that most students had on their computers and could be used to self organize math chats very quickly. Further in our informal conversations with students they liked AOL IM very much and saw it as a "cool" medium in which to construct the math chats. Finally AOL IM is a very basic piece of synchronous chat technology and so it was a good place to start from in order to see what other features we might need to enhance math chats.

The early experience with the PoW-wows was very interesting. There were many interesting things that we began to see about the math chats themselves and several researchers on the project undertook an effort to code the chat data to look for patterns of interaction in the conversation. The chats were also analyzed from a conversation analysis perspective (Stahl 2005a; 2005b; Stahl et al., 2006; Zemel, Xhafa, F, Cakir, 2005; Zemel, Xhafa, & Stahl, 2005).

But beyond the content based research that was taking place in the project there were a number of critical design issues that began to clearly emerge from the chat process. An interesting feature of chat is that it is a medium that moves very quickly. People often do not write whole sentences and ideas flow very rapidly. This is especially true if there are more than two people in a chat. It has become very clear that one thing that was needed was a place where a group could save some ideas that they developed through the chat. They needed a place to store established ideas and a way to organize those established ideas and math facts.

It was also the case that students often missed ideas that others in the group articulated. This is a funny kind of "shunning" that goes on in online chats. On the one hand it may be that an idea is articulated by a member of the group and the rest of the group does not see the idea. On the other hand the idea may fall outside of the main flow of the conversation and because the conversation is moving so fast people do not take the opportunity to respond to the person who's posts fall outside of the main focus of the conversation. Another related process that goes on is that sometimes in these chats two or more conversations would occur in parallel at the same time. This meant that participants needed to let the others know which conversation thread s/he was posting a response to.

Due to the complexity of the problem or time restrictions of participants in many cases the problem solving involves several chat sessions. In later sessions groups would like to review the conversation they had in previous sessions. Thus, they could easily identify the state of the problem solving in their group. This would be especially helpful when group membership changes between sessions as it was the case in our experiments due to coordination problems or drop outs. It would also allow late-comers or participants who missed one session to catch up with the other group members quickly. To support changing membership and multi-session processes a persistent storage of the chat conversation is needed by the students.

Finally it became clear that with many of the math problems the student were doing it was helpful to have a shared graphical representation of the problem and the problem solving. When they did the problem solving together in AOL IM they often drew on a sheet of paper and talked about their drawing on IM. They also began to upload drawings to the Math Forum site so they could share drawings with each other while they talked about the problem.

All of this interaction made it clear that there were some very specific features that such a math chat needs. First it was clear that students need a space where they could put ideas. They need a text box where the questions they wanted to address could be listed, or the ideas they had could be listed or formulas used could be listed etc. Related to this kind of listing function, it became very clear that it would be useful for students to have a place where they could draw or place drawings in order to facilitate the problem solving process. In addition, they need a persistent storage of chat logs to allow late-comers or new group members to fully participate in the group and to provide bridges between different problem solving sessions. Finally the students needed a "referencing" function where they could point to posts in the chat or place in the drawing and bring other participants attention to specific places. These four functions, listing, drawing, storage and referencing became the core of the next phase of a specific chat development.

There were some additional problem solving issues that the team is continuing to think about even as the design of phase two was going ahead. One thing we found in the problems is that there were two dominant modes of discourse in the problem solving. We've labeled these modes expository and exploratory (Stahl et al, 2006). In the expository mode one or more participants are explaining how to do the problem to the others in the group. The others may or may not know how to do the problem solving that the explainer is talking about at that point. In the exploratory mode, all participants are exploring together how to solve the problem and that exploration may or may not be successful. These patterns of interaction have raised the question of whether groups should be mixed or same ability, and then how those groups ought to be scaffolded if they need scaffolding. The research team is continuing to think about these issues as they involve some teachers in the project and plan deeper, more context based explorations of how the kids are thinking about the problem solving.

Second Phase: Using ConcertChat Rooms

The VMT project decided to use ConcertChat, a research chat environment with a shared whiteboard, persistent storage and special referencing tools (Mühlpfordt & Wessner, 2005). In collaboration between the software developers and the educational researchers several versions of the environment have been tried out by the researchers as well as with groups of students. In response to the analysis of the chat logs as well as other information gathered from the moderators, service providers, and the students the environment was gradually modified.

To address the above mentioned four requirements (listing, drawing, storage and referencing) ConcertChat provides a variety of features supporting math chats (see figure 1 for a screen view):

- Listing and drawing: A shared whiteboard allows chat participants to list ideas, formulas etc. and to create drawings using circles, squares, lines, free-forms, text-boxes etc. In addition, participants can place pictures on the whiteboard taken from a gallery, the file system or from any part of the screen using the screenshot feature.

- Storage: All chat messages, editing activities on the whiteboard and all systems messages (e.g. about joining or leaving participants) are stored persistently in the chat environment. Late-comers or new group members can load all previous messages from the room's history. This also allows asynchronous participation in the problem solving process.

- Referencing (1): When someone types a new chat message, they can select and point to a rectangular area or an object on the whiteboard. When that message appears in the chat as the latest posting or as a selected posting, a bold line appears connecting the text to the area of the drawing (see figure 1).

- Referencing (2) Similarly, a chat message can point to one or more earlier textual postings or parts of postings to indicate for example a response to a previous posting. ConcertChat also includes a threaded view of the chat postings that, based on the explicit references between postings, displays them like a typical threaded discussion with responses indented under the posting that they reference.

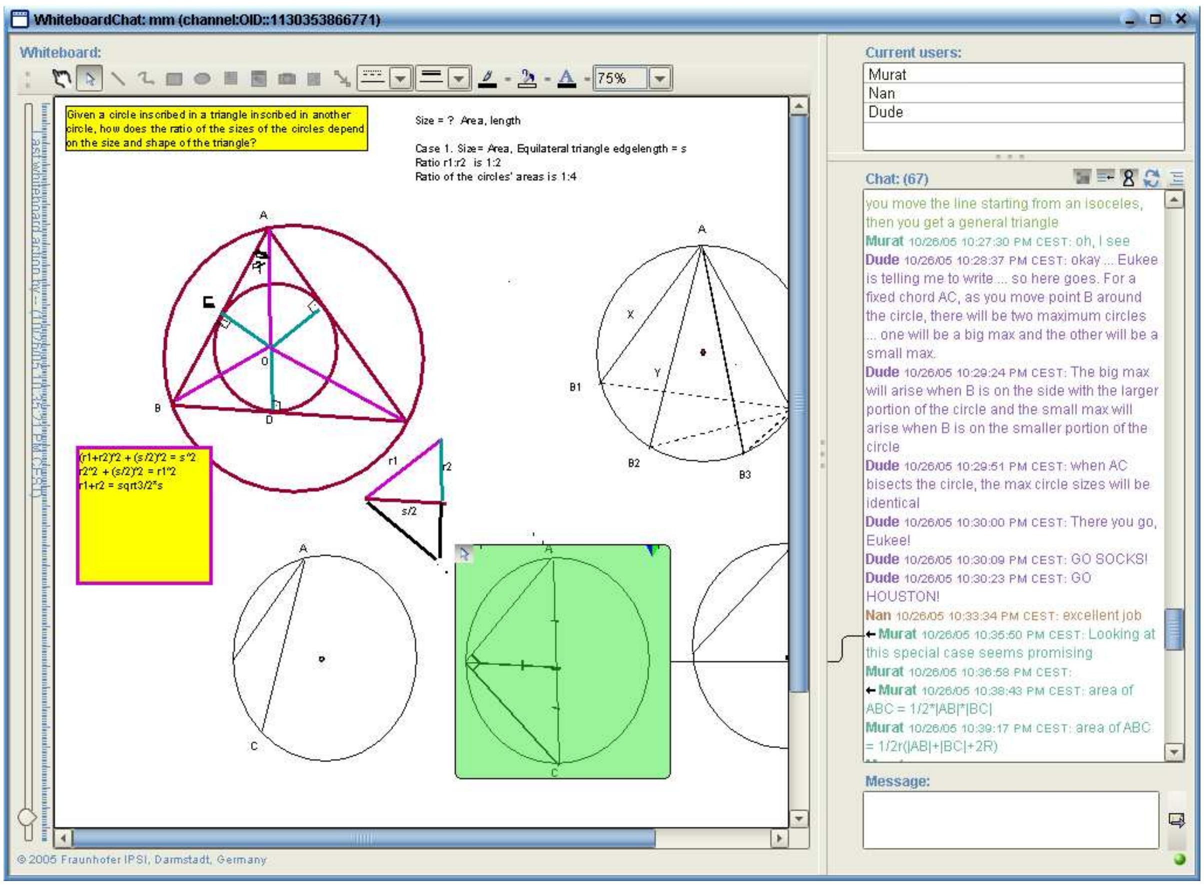

Figure 1. Screen view of a ConcertChat room. One of the messages provides a graphical reference to an area on the whiteboard. The whiteboard also contains textboxes to present the problem and to list ideas and formulas.

In May 2005, a series of chats using ConcertChat have been conducted. Five virtual math teams were formed, each containing about four middle-school students selected by volunteer teachers at different schools across the USA. The teams engaged in online math discussions for four hour-long sessions over a two-week period. They were given a brief description of a non-traditional geometry environment: a grid-world where one could only move along the lines of a grid (Krause, 1986). The students were encouraged to come up with their own questions about the grid-world, such as questions about shortest paths between points A and B in this world.

Technically, the students received a URL for each session where they accessed their group's chat room. From the administrator's point of view a web page provided a list of all available chat rooms and the functionality to create new rooms.

The chats were facilitated by a member of our research project team. The facilitator welcomed students to the chat, pointed them toward the task, briefly demonstrated the use of the system focusing on the graphical referencing tool and then kept generally quiet until it was time to end the session.

The new functionality, the shared whiteboard and the graphical referencing functionality were accepted by the students. However, the degree of usage varied between different groups. Reasons include the lack of an exhaustive manual as well as some usability issues as we learned from the chat logs (some usability issues were mentioned and discussed by the students during the sessions) as well as from our own experiments with the tool.

The instructional design for the experiments with the students included gathering ideas in the individual groups in the first session. In the second session students were asked to reflect on all ideas gathered by all groups and to select those ideas they want to work on. This required some preparation on the side of the moderators in order to collect and prepare the groups' results. Also the initial assignment of students to groups, the distribution of the problem and the handling of drop-outs had to be done by the facilitators. In general, it became clear that an ideal environment should not only provide support for (multiple) chat rooms but also provide support the formation of groups and help to bridge different groups and sessions to allow (self-) organization, awareness of other groups and their problem solving activities and results.

As mentioned above, the ultimate goal of the VMT project is to provide a self-sustaining system which offers a maximum of flexibility to engage in joint math problem solving. For this additional issues have to be taken into account. One critical issue is to support the communication between the groups and a tutor. This includes submitting a solution, requesting feedback on the problem solving process or asking for help if a problem occurs. Another issue is how to communicate the "state" of a chat room to other groups and individuals. This includes questions like: Am I allowed to join that room? Does this group need additional group members? Is the problem already solved? Do they plan to continue this problem solving? From the legal point of view there must be a way to handle rude or even illegal behavior in chat rooms. As a default all activities are stored in the chat history including pictures posted to the whiteboard etc. Questions of ownership, of personal accountability arise (not only) from this legal perspective.

From Multiple Rooms to a Math Community

As a third phase we are currently extending the ConcertChat environment to address the above mentioned issues. As a new component of the system a "Lobby" has been designed and implemented which provides the starting point for all problem solving activities in the math community. Here, students find a list of problems they can work on and all chat rooms they can enter to jointly work on a given or self-defined problem. They also can create new rooms either for new groups or to work with the same group on a new problem. A chat in the lobby supports communication between all students, across groups as well as self-organized group formation. Students can explore all other rooms including rooms where they already have participated and rooms of other groups as long as these are not restricted. This allows communication and collaboration between groups and exchange of ideas, material and group results. For each room a number of fields exists which communicate the state of the room. All online and offline members, the owner, the related problem and other information such as room name or planned session times can be seen for each room. In addition, it is clear from the system's room organization which rooms can be accessed by whom. See figure 2 for a screen view of the Lobby.

With respect to the rooms different types of rooms have been designed in order to meet the different kinds of problems and groups. This ranges from rooms where the problem and the participants are assigned by a facilitator in advance, rooms with a given problem but open to self-organizing groups to rooms which can be used by all students to work on arbitrary problems. Thus both self-forming of groups and tutor-formed groups can be supported. Inside each room the room topic and problem description is available as well as communication facilities which allow the group and the tutor to communicate not only via chat but also asynchronously via email.

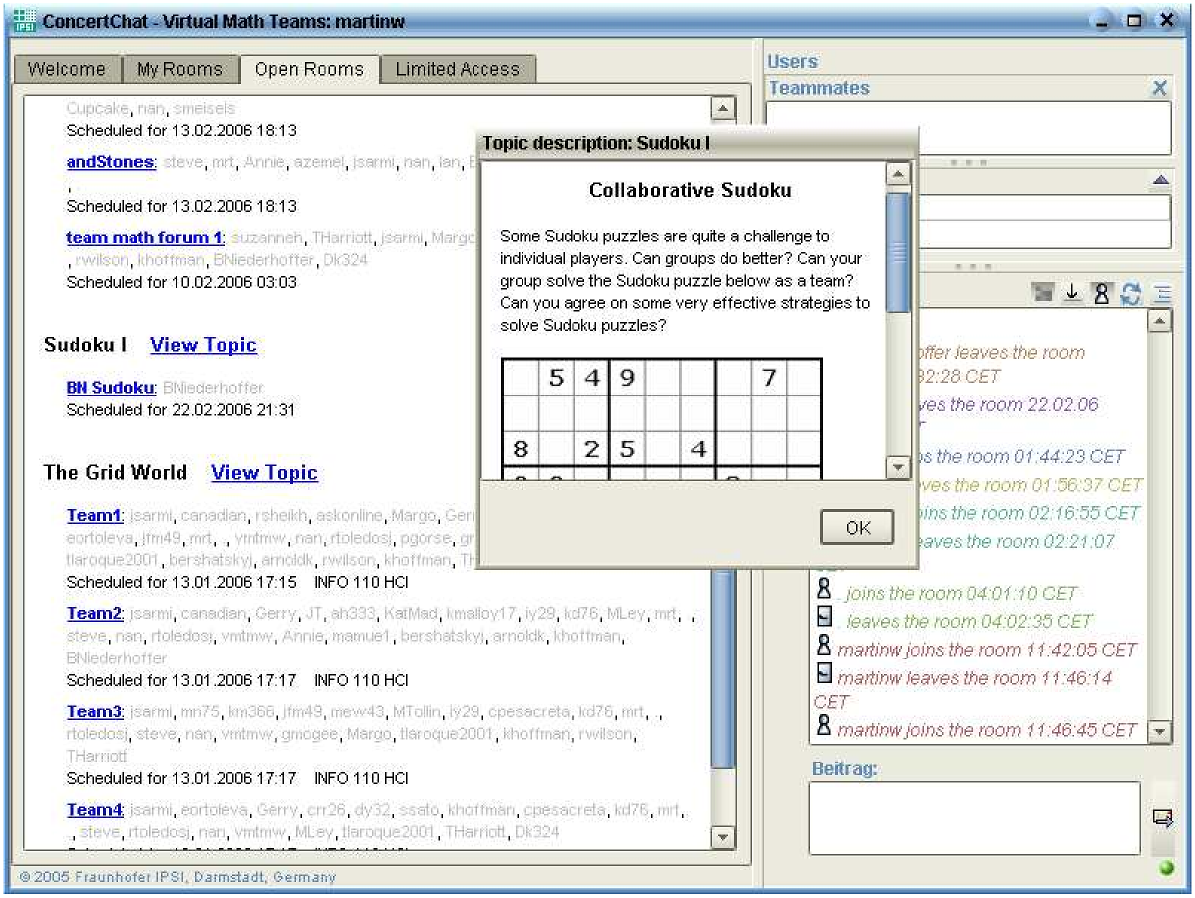

Figure 2. Screen view of the ConcertChat Lobby. On the left side the rooms are organized by access rights (see tabs “Welcome”, “My Rooms”, “Open Rooms”, “Limited Access”) and topics (listing of rooms in each tab). For each room additional information on participants and their online-status, scheduling etc. is displayed. The small window presents the view of one topic, here: a collaborative Sudoku.

Conclusions and Outlook

In the process of designing and using the Concert Chat environment we have made many important realizations about math problem solving and math problem solving online. Math is a subject that is challenging for many students. Using chat takes advantage of a medium that is very popular with kids and one where it is possible to lose oneself a bit in the interaction process. These are potentially good things for the math student. But chat can also be so dissipating that one may not only lose oneself but lose sight of where one is in the problem solving process. And so to that end we have attempted to outfit a chat environment with many of the tools one will need to engage in successful collaborative math problem solving. This includes listing, drawing, storage and referencing to improve the math collaboration in a group as well as various organizational aids to facilitate group formation, access rights and community building.

Further we have begun to work toward a whole community of online problem solvers and problem solving activities. Our experiments with different kinds of math problems have shown us that perhaps some problems need a more structured group in order to fruitfully get through the problem. While other math problems can casually be explored by groups that come together just to talk about a little math. And finally for those groups that want to develop continuity over time they can do so. ConcertChat will provide an environment where individuals might find very different kinds of groups and different kinds of problems. This evolution is very in keeping with the tradition of The Math Forum where different kinds of learners can find the level of support they need in order to improve their ability to engage in fruitful mathematical conversation and become deeper mathematical thinkers.

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