

Piloting TrACE: Exploring Spatiotemporal Anchored Collaboration in Asynchronous Learning

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ABSTRACT

The use of multimedia content such as video is becoming more prevalent in educational environments. However, current platforms for hosting these media provide few collaborative tools to foster social learning between students or request help from instructors. In this paper, we explore the potential of *spatiotemporal anchored collaboration*, and we present a prototype media-playback environment called TrACE that exemplifies the approach. We examine a first design-based research (DBR) pilot deployment of TrACE in two post-secondary courses. Results indicate that students do take advantage of the system's affordances to interact in meaningful ways, though overall student annotation authoring was limited. Using the pilot data, we propose socio-technical modifications for the next iteration in the DBR cycle. Specifically we focus on tools to support instructors' use of the system and for promoting collaboration between students.

ACM Classification Keywords

H.5.3. Information Interfaces and Presentation (e.g. HCI): Group and Organization Interfaces—*asynchronous interaction, collaborative computing, computer-supported cooperative work*

Author Keywords

anchored collaboration; computer-supported collaborative learning; flipped courses; video annotation

INTRODUCTION

Digital media is playing an increasing role in educational environments, particularly at the post-secondary level [39, 43, 17]. Many simultaneous changes have accelerated the adoption of streaming video content in education. A 2010 Sloan Consortium study showed online higher education enrollments that were growing at ten times the rate of face-to-face offerings and projected continued robust growth in online education for the foreseeable future [2], and massive open online courses (MOOCs) have garnered considerable public attention in recent years [31]. In both MOOCs and other online courses, video lectures and tutorials are the most common

form of primary instruction. At the same time, educational institutions are experimenting with blended or hybrid learning environments in which some instruction occurs online, while other aspects take place in face-to-face settings. “Flipped classrooms” [29, 7], in which students independently watch video lectures online prior to class and devote in-class time to collaborative problem-based and discussion-oriented tasks, have become a major discussion point among STEM educators in recent years (see, e.g., [16, 8]). While the educational merits of both MOOCs and flipped classes are still a subject of debate and ongoing research [18, 8], the importance of on-line video in education is undeniable.

A significant challenge in fully and hybrid on-line educational environments is the inability to tailor instruction to the immediate needs of the students when they first engage with content. In these contexts video consumption is conceptualized as an *individualistic activity* and implicitly couched in the behaviorist view of instruction centered around direct knowledge transmission. Within some MOOC platforms (e.g., Coursera) learners may be presented with individual formative assessment quizzes to check their developing understanding, but such tools are not broadly available. Thus, it is no surprise that instructors of flipped courses report that students express frustration about a lack of help while watching videos, and they observe students consuming media passively rather than actively engaging with the content [37]. Further, lack of timely instructor feedback in blended courses may lead students adopt the view that they must “learn it all on their own” and perceive that the course requires more work [38]. Paradoxically, recommended practices in flipped classes, like giving graded entrance quizzes to ensure videos are viewed [30], may exacerbate these perceptions among weaker students who struggle with content of course videos.

In typical video playback tools available to instructors and students, the only means of interacting with the video and other learners is with comments that are often occluded below the visible content. Not only do disconnects between educational media and collaborative spaces inhibit interaction [23], but they make it difficult for learners to engage in more student-centered learning activities like debate, critique, and analysis that are commonly the goals of knowledge building [35] and constructivist learning environments [33, 14].

We see an opportunity to explore the potential of socio-technical systems that explicitly recognize learning from videos as a different process than simply viewing videos. In this paper, we present the initial design and pilot deployment

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of a novel media-playback environment called TrACE, the Transformative Anchored Collaboration Environment. It is intended to enable collaborative annotation and discussion of video content as a first-order learning activity, facilitating more student-centered activities in the online space. In particular, we examine the role of *spatiotemporal anchored collaboration* affordances (ie., the ability for learners to embed discussions at particular locations and times within videos). Thus we use the initial TrACE prototype as a form of technological probe [27], allowing us to explore the adoption and impact of these features for both instructors and learners.

In the remainder of this paper, we first discuss related work in **computer-supported collaborative learning** (CSCL). Next we introduce the initial prototype of TrACE and discuss its design. We then outline a pilot deployment **using TrACE in two post-secondary courses** and **present the study results**. Lastly, we reflect on the implications of these findings for the future design asynchronous video playback environments.

BACKGROUND AND RELATED WORK

We are employing an iterative, design-based research (DBR) approach [4] in the design and evaluation of TrACE. DBR recognizes the significant influence that instructional context has on the ultimate success of new educational technologies and learning environments. DBR espouses a process of progressive refinement, placing early versions of an educational artifact in real learning contexts, with the goal of deriving lessons learned to guide the next phase of design within the socio-technical learning environment [15]. At the same time, DBR recognizes the pragmatic issues of instruction that might limit an instructor's ability or willingness to adopt the newly designed artifact. In this section we synthesize the relevant literature informing the design of the initial system prototype used for the first round of DBR evaluation.

Collaboration and Knowledge Building

Scardamalia and Bereiter pioneered the development of collaborative knowledge building tools [35, 34], namely CSILE (later, Knowledge Forum). Central in knowledge building environments is the ability for learners to engage in discourse—positing ideas to the group along with supporting evidence. Importantly, these tools also allow learners to collaboratively evaluate, discuss, and augment each others' work to advance the whole class understanding of phenomena being learned [34]. Knowledge Forum and other modern systems (e.g., Science Online [19]) explicitly promote the salient forms of discourse in the target educational context. In this work, we aim to stimulate class-level discourse about instructional media so that learners actively engage and help each other to a deeper understanding. Thus, we adopt and adapt features from other knowledge building environments like procedural facilitation and categorization of contribution types to guide students toward productive forms of discourse.

Guzdial and Turns define *anchored collaboration* in CSCL environments as embedding, or anchoring, collaboration tools near the media to which they refer [20]. Early anchored collaboration environments demonstrated that placing links to threaded discussion areas within static Web pages of instructional content increased the likelihood that students would

engage in collaborative discourse and increased the quality of that discourse [23]. In this paper, we extend this approach for time-based instructional media (e.g., videos) and anchor collaborative discussion spaces in both “place” and “time” within the media itself to preserve the original context in which discussions begin. Thus, we refer to this approach as *spatiotemporal anchored collaboration*.

Annotation Systems

The HCI and CSCL communities have a long history of exploring the use of multimedia and annotation platforms as vehicles to provide instruction. In the mid-nineties and early 2000s researchers developed a wide variety of computational tools to support students in using multimedia for learning course content (e.g., MediaText [25], Classroom 2000 [1], and Goal-Based Scenarios [36]). Classroom 2000 was designed to capture course content through ubiquitous computing techniques to be made available for students to later access asynchronously over the web [1]. It employed instructor-specified annotations within the media as bookmarks, and allowed learners to contribute additional annotations on separate course wikis [22]. While evaluation studies of Classroom 2000 showed promising results, the level of learner interaction within the environment was limited by the web-based development techniques available at the time.

In the intervening decade, there has been an explosion of Web 2.0 interfaces, social and crowd-sourced platforms, and a generation of learners who have grown up interacting with the web as co-creators of content [6, 32]. Accordingly, there has been a renewed interest in collaborative annotation environments for various documents and media (e.g., [47, 44]). Zyto et al. argue that this is due in part to the fact that “the socio-technical environment of the classroom has evolved to the point where the barriers that were encountered by earlier annotation tools have lowered enough to be overcome by motivated teachers and students” [47]. Zyto's text document system employs a spatial annotation technique, and their evaluation efforts show significant increases in the amount of student-to-student discourse occurring online [47].

Recent work by several different research teams has also revisited annotation of course videos. Wong's system, EVA, provides a collaborative temporal annotation system allowing learners to associate comments with specific time-segments in a video [45]. The Choreographer's notebook, developed by Carroll et al., allows users to asynchronously attach critique feedback to relevant regions of videos recorded during dance rehearsals [40]. While both dancers and choreographers can contribute annotations, researchers found that the vast majority of annotations were unidirectional from the choreographers to the dancers [12]. Kim's Toolscape [28] provides an interface for navigating workflow annotations within online tutorial videos. Toolscape's playback system leverages annotations as bookmarks that allow for quick indexing to important parts of the tutorial, but the annotations themselves are not intended as points of discussion between users. Lastly Zaption [46], a commercial start-up venture, allows instructors to place a variety of interactive widgets like discussion boards and quiz questions at specific points in instructional videos. Zaption's discussion widget (when enabled by the

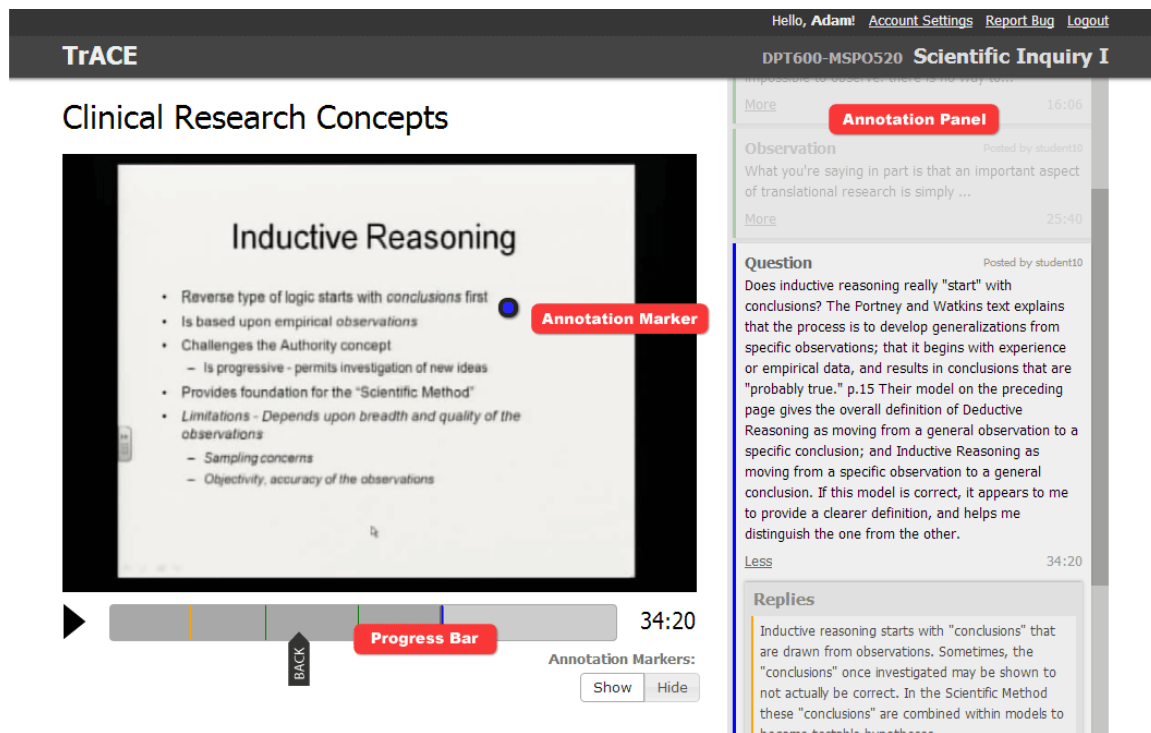


Figure 1. A student view of watching a video in TrACE

instructor) associates student posts with the video's current timestamp, but comments and replies are free-form and do not explicitly aid learners in the task of authorship.

Our design of the TrACE system synthesizes ideas from each of these systems and differs from prior work in one or more of the following ways:

- TrACE provides robust referential comments, associating annotations with both a timestamp in the video *and* a specific location inside the 2D media frame at that timestamp.
- Contributed annotations serve as bookmarks in the media and allow quick navigation and non-linear access.
- TrACE supports both asynchronous and synchronous collaboration between users.
- Top-level annotations in TrACE are treated as starting points for group discussion, allowing others to reply directly and collaboratively make sense of the media.
- Annotation authoring in TrACE supports categorization and directed reflective prompts to enhance the quality of the resulting discourse between users.

In the next section, we illustrate each of these design features as they appear in the current TrACE prototype.

OUR DESIGN PROTOTYPE

TrACE is implemented as a web application using HTML5, JavaScript, PHP, and AJAX. This implementation choice allows for write-once-run-everywhere functionality in modern web browsers, including those on mobile devices. This ensures a wide degree of flexibility for how students view the media associated with a course, and it provides a seamless

interaction experience as students and instructors move between their various computing devices.

Upon logging into TrACE, learners are presented with a list of courses in which they are enrolled. Students can then navigate to a specific course and view its associated videos. Once they select a video from this list, they are presented with the media playback interface illustrated in Figure 1. This screenshot illustrates many of TrACE's core features.

Annotation Panel

The annotation panel at the right of Figure 1 displays all annotations in the system for the displayed video. Rather than hiding annotations below the video, annotations are placed alongside the media to maximize the learner's ability to refer back and forth between the media and annotations.

Each annotation carries a timestamp indicating where its author placed it within the video. During playback, timestamps are used to automatically position the panel's scroll bar such that the annotations of temporal relevance to the video's playback position are always visible. Annotations that are not currently relevant are also faded to reduce visual clutter, and replies are only shown when the user explicitly views the top-level annotation. These techniques leverage progressive disclosure to minimize cognitive workload [24] and focus the viewer's attention on the annotations of immediate importance. It also enables learners to quickly evaluate whether another person has asked a similar question at this point in the video.

Further, annotations are categorized and color-coded in the annotation panel and playback interface (e.g., "Questions"

are blue, and “Links” are red). This simplifies recognition of the type of contribution within the system.

Annotation Markers

In addition to providing information about an annotation’s temporal location within the media (i.e., timestamps in the annotation panel), TrACE also provides referential capabilities for learners, allowing them to place a visual marker at or near an item of interest in the video frame. For example, a student might annotate a confusing term or definition, or the introduction to a new concept. Thus, not only are annotations tagged with respect to when in the video they are made, but they are also tagged as to where in the 2-dimensional video frame the poster left the annotation using a circular marker. In Figure 1 an annotation marker appears near the word “first”.

Annotation markers are displayed as though floating above the media and are visible for a short, but predictable, window of time on either side of their original timestamp. As the video plays, these markers appear and disappear based on which annotations are currently relevant to the point the student is at in the video. This unobtrusive technique allows for annotations to appear as though they belong within the content of the video while also giving an indication of the social interactions which are taking place at a given position.

The expository and/or demonstrative nature of most educational videos motivates the need for our spatiotemporal approach. It enables students to refer to and ask about steps, items, and concepts in the moment, which is a critical element in developing both conceptual and procedural understanding [10]. Further, anchoring comments in space and time allows users to visually indicate specific, relevant details of their questions. Preserving this referential context about the initial annotation increases the likelihood that subsequent viewers will be able to understand the original point made and engage meaningfully in authoring a reply.

Progress Bar

TrACE employs a context-aware progress bar beneath the media that not only indicates the learner’s current playback position within the video, but also the relative position of all annotations placed by others in this video (seen as the colored vertical bars in the progress bar in Figure 1). This can serve as an advance organizer [3], giving students an indication of which annotations are present and cuing their attention to sections of the video where significant activity has taken place. Further, this visualization provides instructors with an immediate formative assessment tool [11], allowing them to evaluate which parts of the media may need additional discussion.

The video player and annotation markers, the progress bar, and the annotation panel are designed such that interactions in one area affect all others. For example, advancing the progress bar will move both the video and the annotation panel to that position. Further, clicking on an annotation will cause the video and progress bar to jump to the location where that contribution was made. Thus, each annotation serves as a bookmark; learners are able to index into the media to points

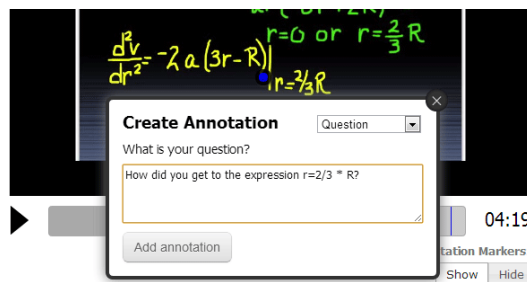


Figure 2. Creating a new annotation

of interest rather than being restricted to viewing the content in a strictly linear fashion [13].

Creating a New Annotation

As a user is viewing media in TrACE, he or she can contribute new annotations as the need arises. Users construct new annotations by clicking the mouse at a specific position within the video frame (or tapping the screen on a mobile device). This mimics the pointing gesture a student might make in a classroom while saying, “I don’t understand where this value came from in the equation.” The location in which the student clicked or tapped provides the new annotation’s anchor point for both where and when it occurred.

When a user initiates an annotation, a new marker appears on the video and the user is presented with a multi-step wizard to scaffold the creation of an annotation (a simplified view of the process is shown in Figure 2). Each of the different annotation types features a customized dialog that assists students in the process of contributing a productive question, comment, link, etc. These question types and prompts are determined based on instructor input prior to the term. The goal is that, rather than posting generic comments, learners are guided to think through specific aspects of their contributions. Similar guided approaches to reflection have been shown to produce more educationally effective discourse in other collaborative learning environments [35, 20, 5].

Viewing an Annotation and Replying

Once submitted, the new annotation automatically appears and becomes the starting point for a new anchored discussion in the annotation panel to which other students and the instructor can post replies (see Figure 1). Figure 3 illustrates how learners and instructors can then view existing replies for any given annotation as well as contribute a new reply. When an annotation is clicked (either by the marker within the video frame or by the annotation in the panel), the video is advanced to the point in which the annotation was added and then paused. The annotation then expands within the panel to show all replies (which are also categorized) along with a text area that can be used to post a new reply. The reply wizard follows the same conventions as creating a new annotation in order to create constructive and meaningful replies.

SPRING 2013 PILOT STUDY

During Spring 2013 we deployed TrACE in our first DBR iteration. The early TrACE prototype was piloted in two courses, Scientific Inquiry and Calculus I, both of which used

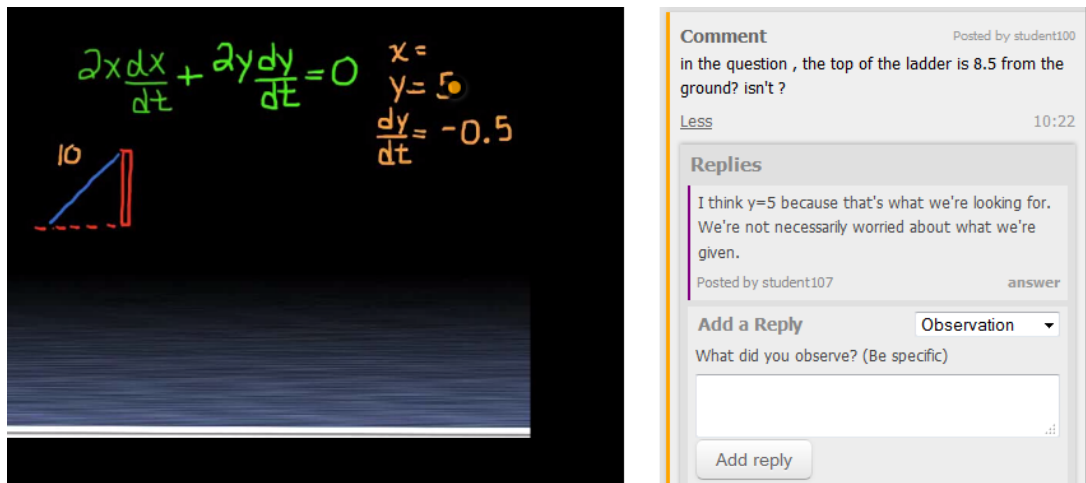


Figure 3. Adding a reply to an existing annotation

videos as an integral component of instruction. Scientific Inquiry (SciInq), a graduate level course taken by masters and doctoral students in the rehabilitation sciences, provides an introduction to research methods used in physical therapy. This course was taught in a hybrid format, with the class meeting face-to-face every two to three weeks; in the intervening weeks, students were expected to watch video lectures recorded by the course instructor. SciInq videos were predominately recorded in a lecture-capture format showing static slides interleaved with full motion video of the instructor at a podium. Of the 63 students enrolled in this course, 41 agreed to participate in the study data collection, and 35 were active¹ within TrACE. Videos were simultaneously available in both the course LMS (ie., Blackboard) and TrACE during 14 weeks of instruction, and students were allowed to view videos using one or both systems.

Undergraduate students from two sections of an inverted/flipped Calculus I (Calc) course also participated in the pilot study for a 5-week period at the end of the semester. Videos in Calc took on an interactive format, where **slide-based presentations** with minimal pre-existing content were written upon by the speaker with a stylus while explaining mathematical ideas. Other videos made use of interactive simulation software to demonstrate the relevant concepts. Of the 45 students enrolled in these sections, 30 consented to participate in the study, and 28 of them were active in TrACE. Throughout the entire semester, students in the inverted Calc classes were expected to view one or two 10–15 minute long videos before each class meeting period. During pilot study data collection at the end of term, videos were only available through TrACE and were no longer available through the LMS as had been the case earlier in the semester.

Beyond obvious differences between the level and content of these courses, the instructors adopted different approaches to the integration of videos. Table 1 outlines a number of these differences. While students in Calc were expected to watch more videos per week, the videos were much shorter

¹We define *active users* as those who consented for the study and viewed at least one video in TrACE.

Table 1. Video Properties by Course

	Sci Inq	Calc
weeks of instruction with TrACE	14	5
# videos available	22	14
average # videos per week	1.57	2.8
minimum video length (mm:ss)	17:52	5:25
maximum video length	56:46	17:59
average video length	36:50	11:38
mean expected viewing time per week	54:01	32:34

in length. Notably, the shortest video in SciInq was roughly equal in length to the longest Calc video. All told, the average expected viewing time per week² for Calc students was about half that of SciInq students.

Differences in course expectations seem natural given that SciInq students watched videos in lieu of attending class, whereas Calc students viewed videos on their own time to enable hands-on activities during normal class sessions. Other pedagogical variations that arose due to differing course content, teaching strategies, and the needs of students served as variables with which to study usage and adoption of TrACE. In this pilot deployment, we also needed to balance pragmatic concerns instructors had about the new technology with our research goals. Nonetheless, the SciInq and Calc courses provided interesting (and somewhat typical) use cases for asynchronous educational videos and thus were good environments in which to pilot the system.

We posed the following exploratory questions:

- Q1** How and to what extent do students make use of the collaboration tools within TrACE?
- Q2** How and to what extent did the collaboration tools support interactions between users?
- Q3** What socio-technical limitations can be identified in the pilot deployment to inform future iterations?

²Calculated as the total running time of all videos in a course divided by the number of weeks of instruction using TrACE.

Table 2. Session Activity by Course

	SciInq	Calc
Total number of sessions	393	363
Avg # sessions per student	11.2	13.0
Avg # sessions per student per week	0.8	2.6
Avg session length (mm:ss)	32:04	15:42
Avg player events per session	17.2	15.6

The first two questions explore the ways in which users collaborate within TrACE, while the third focuses broadly on the interaction between instructional context and the system.

Data Collection

In both courses, students were allowed to use TrACE regardless of whether or not they participated in the study. Data presented here is from only the consenting, active participants and is masked to preserve anonymity. User interaction in TrACE was recorded automatically for both server-side events (logging in, viewing a course, opening a video) and client-side events (playing/pausing a video, seeking within a video, viewing and authoring annotations). 13 action types were logged along with relevant details about each like timestamps, user ids, etc. In total, we recorded 16,347 such actions. We also aggregated the actions for each student into viewing sessions. A *session* in this context is defined as when a student begins viewing a video and continues until an action that takes the user off the video page (e.g., returning to the course media page, logging out of TrACE).

Logfile data provided quantitative interaction data, but we also examined student and instructor contributions in the system to develop a qualitative understanding of participants' use. Lastly, we administered an online survey to student users at the end of the term to gather additional feedback on TrACE.

Results

Students in the two courses exhibited distinct viewing patterns. In total, SciInq students viewed videos 425 times, while Calc students generated 418 video viewing events. However, given that Calc students used the system only for the last third of the term, they generated significantly more views per week per student on average (2.99) than their SciInq counterparts (0.87) ($t(38.1) = -4.92, p < 0.001$). On the whole, Calc students also demonstrated more consistent viewing patterns week-to-week up until final exams where viewership dropped off. SciInq students, on the other hand, showed more erratic viewership patterns in TrACE.

Session-Level Interactions

Aggregating log events at the session level provides another perspective from which to view the use of TrACE. Table 2 presents additional details about students' activity levels in viewing sessions. Calc students generated significantly more viewing sessions per week on average than SciInq students ($t(39.2) = -4.52, p < 0.001$). Further, SciInq students generated markedly fewer viewing sessions per week than would be expected given the number of weekly assigned videos (see Table 1). The average SciInq session was shorter than the average video length in the course, implying that most sessions ended before the entire video was played. On the other hand, Calc students' typical sessions lasted about 35% longer

Table 3. Annotation Related Statistics by Course

	SciInq	Calc
Total number of annotations	29	46
% of annotations contributed by students	62%	43%
% of videos with annotations	36%	64%
By Conversation Threads		
Total number of conversation threads	14	30
Avg # threads per video	0.64	2.14
Avg thread length	2.07	1.53
% of threads initiated by students	92.9%	40.0%
Student Authorship/Viewing Behaviors		
% who authored an annotation or reply	8.6%	21.4%
% who viewed annotations, but didn't author	62.9%	39.3%
% who watched videos, but didn't view annotations	26.6%	39.3%

than the average course video's length, suggesting the potential of activity in the interface beyond simple playback. These trends held when we examined students' total session length per week, with Calc students viewing videos in TrACE for considerably more time per week than those in SciInq (40:44 vs 22:46, respectively). While the average number of playback interface events in a typical session was similar in the two courses, Calc students were significantly more active in their interactions with the media when controlling for session duration ($t(636.4) = -2.78, p < 0.001$).

Use of the Annotation System

Beyond basic interaction data, we examined how participants made use of the TrACE annotation system. Table 3 presents quantitative data about annotation authoring. The remainder of this subsection explores example annotation threads within the system to highlight its use in the two courses.

Pointing and Asking: In both courses, students and instructors took advantage of TrACE's spatiotemporal features by leaving annotation markers near content within the video, where in at least some cases the position of the annotation markers resolved ambiguities for the reader. Calculus students left annotation markers near diagrams being discussed or near variables of interest in equations. For example, the interaction depicted earlier in Figure 3 shows student100 expressing confusion about a portion of a video where the professor is solving a related rate problem about a ladder sliding down a wall. From the student's comment alone, it is not clear to which part of the currently visible content within the video frame he is referring. The associated annotation marker, however, removes all doubt as it is placed directly on top of the $y = 5$ in the visible content. This enables student107 to recognize that student100 is wondering why y is not 8.5 instead, and allows her to respond based on her understanding of the situation.

Additionally, we noted instances where the physical position of the annotation markers was not essential to the posted content; however, the temporal dimension played an important role. In particular, SciInq students often asked more general questions about the current topic of discussion. In these cases the particular visible content in the video frame was not of direct relevance. In Calculus, one instructor would often place annotation markers in the margins of the video at particular times when challenging students to try working a problem:

[Instr4] Comment: *You should try this on your own - pause the video and then check your work.*

Deliberate Seeding: One of the Calculus instructors made a regular and deliberate effort to seed the environment with potential points of discussion for the students. As a result, videos from Calc were more likely than those from SciInq to contain at least one annotation. For example:

[Instr4] Question: *Is a left rectangular approximation always an under-approximation and is a right rectangular approximation always an over-approximation?*

Unfortunately, many of these instructor contributed annotations received no student replies, limiting the instructional impact of these meta-cognitive reflection points. We posit that students may have considered these annotations merely rhetorical questions from the instructor, rather than questions to which a response was needed.

Student-to-Teacher: A large proportion of the student contributed annotations garnered only a single reply from the course instructor, with no other students taking part in the conversation whether or not the instructors' intention was to facilitate or terminate the interchange. For example, in the exchange below from Calc, the student directly addresses the question to the instructor using the pronoun "you." The instructor's response is an invitation for further discussion among the class, but goes nowhere.

[Stu110] Question: *how did you get $Pi \cdot r^2 h$?*

[Instr4] Answer: *What is the volume of a right circular cylinder?*

This type of interaction was most frequent in SciInq where a majority of the top-level annotations were contributed by student users, and nearly all these threads began with a question or comment from a student followed by an answer from the course instructor. One interaction like this is shown below, where a student provided feedback to the instructor, asking for a specific example.

[Stu10] Comment: *An example might be useful right about now ... this is hitting the limit of my capacity to relate the various pieces in the abstract ...*

[Instr1] Answer: *Operational Definition Example - Assessment of Pain: Pain will be assessed using a VAS (Visual Analog Scale) The patient will be given a paper copy of the 10 point scale that ranges from 1 (no pain) to 10 (unbearable pain). The patient will place a mark on the pain scale to indicate his/her choice. The closest numerical value to the mark will be recorded as the pain indicator for that sample.*

In fact, on several occasions SciInq students explicitly began their posts with "Dr. XXX, ..." Unfortunately doing so may signal to other students that they need not reply, potentially preempting meaningful collaborative discourse. Students appear to be naturally transferring the face-to-face practice of directing their individual questions to the teacher, rather than posing the question to the whole class for discussion. It may be necessary to help students adopt a broader notion of their audience when authoring posts.

Student-to-Student Collaboration: While there were some instances of student-driven discussions within TrACE, they were a small minority and far less frequent than we had anticipated. In almost all cases such threads did not exceed a

single reply. All told, only about 20% of Calc students authored an annotation, including both top-level contributions and replies. The remaining 80% of students were evenly split between lurking behaviors (viewing, but never posting annotations) and seemingly ignoring the annotations all together. Less than 10% of SciInq students authored any annotations, but the majority viewed at least some of the existing annotations as they watched the videos. Only about a quarter of SciInq students viewed all videos without examining annotations. Encouraging more student interaction is a clear obstacle to overcome if the goal is to sustain discourse between students about course material in the future. We return to this and other implications in the discussion section.

Student Feedback

In addition to data collected through TrACE, sixteen students ($n = 4$, Calc; $n = 12$ SciInq) responded to our end of semester survey. Their responses to the survey questions provide limited opinions about TrACE, but when asked to describe what they liked responses could be grouped into two categories: one applying directly to TrACE and one related to video-based instruction in general.

Students liked the interactivity of TrACE ($n = 5$) (i.e., the ability to ask questions, to receive feedback, and to read comments), its ease of use ($n = 6$), and the general ability to view/re-view material ($n = 3$). When asked to compare experience with TrACE to watching course videos posted on YouTube, a Calc student reflected:

Advantages for both video platforms: the ability to pause and replay videos if something was not fully understood. I personally enjoyed the ability to full screen on youtube. However, I liked the TrACE platform more b/c I was able to ask questions.

Respondents indicated a high degree of comfort with TrACE, without significant instruction on its functions. 12 of the 16 (75%) were confident that they knew how to create new annotations and 11 of them were confident that they knew how to reply to existing annotations in TrACE. However all but 4 students indicated that they had never authored one. When asked why they had not contributed, common responses were:

I didn't have any questions during the viewing of the videos.

I have contributed one time but I feel that the power points are really self explanatory.

Students' criticisms of TrACE centered on the lack of some common video UI tools in the prototype used for the study (e.g., lack of a zoom feature and volume control widgets). Other suggestions for improvement included thread notifications and the ability to "follow" posts, embedded quizzes, and integration with the university LMS. Some survey respondents also felt that instructors should require students to post comments or questions in TrACE or somehow otherwise encourage more participation.

Student responses on open-ended questions also discussed logistical issues with the course content that influenced their behaviors. For example, a SciInq student brought up issues related to the video length and its presentation style:

The videos on trace work much better than blackboard echo. I do not use the tool properly, though, because the video lectures are just the professor reading the PowerPoint slides posted to download. It is

quicker to read the slides than watch the video. I only use the video for the lab assignments.

DISCUSSION AND IMPLICATIONS

Classrooms are complex sociotechnical environments that make it difficult to isolate the multiple variables influencing collaborative student behavior [41]. Nonetheless, these results highlight pedagogical and technological issues to be considered in order to improve opportunities for spatiotemporal anchored collaboration, to support learning, and to provide a direction for the next iteration of TrACE.

Pedagogical Issues

The limited degree of collaboration between users during this pilot study raises a number of questions about general absence of collaboration observed in both courses. One possible explanation could be the students' academic background in the sciences. Guzdial et. al. [21] attributed the lack of collaboration between students enrolled in math, science, and engineering courses to competition inherent to these programs, the reluctance to seek help, and the perception of single correct answers as the discipline standard. The students enrolled in this study fit a similar profile. SciInq students, studying rehabilitation sciences, have extensive studies in the sciences. Similarly, students enrolled in Calc I are predominantly science, math or engineering majors.

Anecdotal reflections from the instructors suggest that the limited student collaboration in TrACE may not be due to lack of questions about content. For example, at the beginning of each class one of the Calc instructors regularly asked students to respond to the prompt, "state three questions that you still have about the video." In this formative assessment, students raised considerably more questions than were in TrACE for the same video. Thus, the limited interactions may be due to students' unwillingness to expose their lack of understanding to the class as a whole in the semi-public TrACE environment. While prior CSCL environments have demonstrated that online media can reduce classroom conversation inhibitions (see, e.g., [26]), design features of TrACE—namely, usernames derived from student first and last names—may have unintentionally amplified traditional classroom anxiety about asking questions given today's concerns about the longevity of social media posts.

Both of these possible explanations speak to classroom culture that may best be addressed through explicit discussion of classroom norms and social expectations.

Instructor Intentionality

Instructors play a key role in students' adoption of technologies. The sparse collaboration within TrACE during this pilot study suggests a need for more intentional integration between online activities in TrACE, instructors adoption practices, and face-to-face classroom activities. Stahl et. al. [42] highlight the importance of considering CSCL technologies as part of the "larger motivational and interactive context." As first time users of the system, our instructors were experimenting with both online content delivery and the TrACE platform during the pilot study. As a result, clearly articulated plans for integrating TrACE into the course structure

and modifying their own teaching practice was absent from this pilot study. Instead, both instructors viewed TrACE as a means of addressing a perceived shortcoming of using videos for instruction—the inability of students to ask questions as they are viewing the content for the first time.

To enhance the opportunities for spatiotemporal anchored collaboration to positively impact student learning, we see a need for instructors using TrACE to set clearer expectations for student interactions on-line and to integrate asynchronous discussions with in-class instruction. Instructors need to be aware of how their own behavior in the system can impact the quality of student interactions and send tacit signals about the locus of authority and knowledge in the online environment. For example, the phrasing of an instructor's replies may either encourage extension or termination of a discussion.

Ultimately, we believe that instructors using TrACE need to explicitly establish and communicate a rationale for why the online interactions are valuable to students both individually and as a group—something that was largely absent in both courses during this pilot test.

Technical Issues

In addition to social issues that arose here, we also identified some technical limitations in the prototype that can be resolved prior to future deployments.

Tools to Promote Collaboration

One of the difficulties within any asynchronous collaboration environment is recognizing what happened since the user last logged in. In course settings like those here, many students watched videos once and then never returned, regardless of whether or not important questions or conversations had taken place since the original viewing. TrACE did not provide any visual clues as to which videos had recent annotation activity for student viewers, making it difficult to entice students to revisit videos. In fact, students mentioned social media inspired features as a potential improvement to TrACE on the end of term survey; for example:

Like on Facebook, when someone comments on a post your made you are notified that a response has been made to your post. And an option to [c]hoose whether you want thread notifications or not.

Features like thread following and activity notification emails would provide more activity awareness for students and may propel them back into the system. Not only might this encourage them to revisit media, but ultimately this may increase collaboration activities like viewing annotations and extending existing threads with new replies.

To address students' reluctance to expose their lack of understanding to peers, future prototypes should give authors the ability to anonymize annotations on a post-by-post basis. This may alleviate concerns about posting questions or comments about which students are not completely confident.

Instructional Supports

The results of this pilot also suggest some areas where TrACE did not fully support the instructors' needs. First, we saw that instructors contributed annotations for unique reasons, like attempting to seed student discussion, but the version of TrACE

in this study provided a uniform set of annotation tools to all users in all courses, regardless of the user's role. Instructors need greater flexibility to adapt the set of available annotation types to fit the kinds of discourse best suited to their discipline. Further, annotation types that help users distinguish posts from students versus the instructor may help direct students' attention when necessary. Providing an expanded set of annotation types tailored to individual courses may help instructors integrate TrACE more easily. For example, book-marks in the video could provide the instructor with a way of creating an advance organizer for the video, or allowing instructors to insert a pause point in the video with a specific prompt for student response may be one way to eliminate uncertainty as to whether or not a question is rhetorical.

Limitations and Future Work

The nature of this pilot study naturally serves as a limit to what can be said about TrACE and spatiotemporal anchored collaboration in general. Because neither course exclusively used the system for the entire instructional term, students and instructors may not have had time to establish norms around its use that would increase interaction. Further limited data about instructor intentions and student motivations was available, partially due to low survey response rate. However, broad generalizability is not the primary goal at this early stage. Instead, the results of this study have identified numerous revisions to both the TrACE system and pedagogy to be explored more formally in the following DBR evaluation.

We have already incorporated many of the interface modifications mentioned in the previous sections (e.g., customized annotation types, anonymous posting) and are collecting new data about system use in a wider variety of course settings. In particular, we are deploying the system as the sole video content source with multiple courses and different instructors of the same course for the full academic term. This will provide a broader understanding of variations in course integration and the impact of those variations on student activity in TrACE. We have three primary questions going forward: (1) What aspects of system usage correspond to higher student performance? (2) What types of collaborative discourse take place in TrACE? (3) To what extent do instructors intentionally integrate TrACE into their practices, and how does this shape student participation and collaboration in the system?

The first two questions focus on students and their interactions. First, we intend to correlate measures of user engagement derived from system logfile data to study how students' viewing and annotating patterns in TrACE relate to various course performance metrics (e.g., exam grades, final course grades). These metrics will help us quantify both viewing behaviors and collaboration activities, and this analysis will help us uncover which behaviors align with greater student performance. Beyond the quantity of posts, we also will assess the quality and types of annotation content using a qualitative framework derived from that of Borge and Goggins [9]. This tiered framework allows for evaluative distinctions to be made between posts—for example, those that share unsubstantiated facts, attempt to revoice content of others, synthesize multiple concepts, or represent metacognitive reflection. In addition to uncovering a great deal about student's

observed behaviors, these data will also be used to purposefully sample student users for follow-up interviews to examine their perceptions of the overall instructional environment.

The last question specifically addresses the role of instructors within a socio-technical system and the impact of their instructional decisions on students' interactions. To this end, instructors will participate in a weekly journaling activity to reflect on the trajectory of instruction during the past week, the impact of TrACE on teaching and learning, and any instructional changes planned for the upcoming week. In addition, instructors will be interviewed at the end of the term about their experiences, using their own journal entries as an artifact on which to elaborate. Coupling a qualitative thematic analysis of these data with the quality of annotation content and student performance data may help us understand how to encourage the types of classroom integration practices and student participation in TrACE that enhances learning.

CONCLUSION

As educational innovations continue to grow the use of web-based media, technical advancements in collaborative learning tools must also be made for both small scale environments like flipped classes and large scale environments like MOOCs. In this paper we have outlined the initial design of TrACE, the Transformative Anchored Collaboration Environment, and presented results of a pilot study involving two different post-secondary courses. We have extended prior work in CSCL to include *spatiotemporal anchored collaboration*, and TrACE exemplifies a set of interaction techniques for enacting it. Results of our pilot study suggest a variety of factors that may influence students' usage patterns in the system and highlight the need for additional pedagogical and technical supports to foster interaction and collaboration over course media delivered asynchronously online.

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