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An Instrumental Co-Genesis Approach to Developing an Online Practice-based Environment for Teacher Education

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Abstract: Lesson*Sketch* is an online, multimedia-based learning environment that supports practice-based teacher education. A work in progress since the development of its initial components in 2008 and its launch in 2011, Lesson*Sketch* has served more than 3,000 users, consisting mainly of teacher educators, in-service teachers, and pre-service teachers. In this paper, we show how we have applied an instrumental co-genesis approach to the design of Lesson*Sketch* in order to address its users' changing needs and their difficulties using Lesson*Sketch*. The instrumental co-genesis approach consists of multiple design-utilization cycles, each of which helps us understand how users' needs develop and how they deal with difficulties using Lesson*Sketch*, thus informing how we improve the environment in the following cycle. Through this work, we have developed a number of design principles that can be useful for the development of online learning environments that support practice-based teacher education.

Introduction

Lesson*Sketch* (www.lessonsketch.org) is an online environment for practice-based teacher education. It was first made public in 2011, though some of its components date back to 2008. The work of developing the environment has presented us with the particular challenge of identifying design principles that would help us create technological resources, models, and tools to support its use by teacher educators who in turn use the platform to support learning for both preservice and in-service teachers. This paper describes an *instrumental co-genesis approach* (Rabardel, 1995; Béguin & Rabardel, 2000) to the design, development, and improvement of Lesson*Sketch*. This approach consists of multiple cycles, each of which involves the analysis of users' interactions with the environment, with the objective of learning about their needs and the difficulties that they experience. This feedback is then used to inform the improvement of existing features and the design of new features of the environment. Then, working within this newly modified environment, users encounter new difficulties and communicate new needs, which the designers and developers respond to, and the cycle continues.

The instrumental co-genesis approach to the design and development of complex environments, such as Lesson*Sketch*, however, requires long-term commitment (e.g., years) from both the designer and the user (Béguin & Rabardel, 2000). Hence, it is not surprising that there has been little empirical research on this approach. In this paper, we describe our development of Lesson*Sketch* as illustrating an instrumental co-genesis approach to the design of an online environment. Lesson*Sketch* can therefore be seen as an example providing a useful context for studying this approach, as the design of the environment has gone through multiple cycles, with different groups of users (e.g., preservice teachers, in-service teachers, teacher educators). In this paper we discuss a number of cases of teachers and teacher educators' use of Lesson*Sketch* to show how the instrumental co-genesis approach has helped us improve the design and development of the platform. The consideration of those cases enables us to propose a number of design principles, which we have derived from our work over the past several years, that could be useful for the design and development of other online, professional learning environments.

Theoretical Framework

Researchers in many areas, from occupational psychology to anthropotechnology, have been interested in *activity theory* (Engeström, Meittinen, & Punamaki, 1999; Kaptelinin & Nardi, 2006; Leontiev, 1978; Vygotsky, 1978) and used it as a theoretical framework to describe and explain human activities, and professional work, in particular. Those scholars consider human activities as phenomena that are complex and socially situated. More specifically, they build on the Vygotskian notion that a human subject's work (e.g., a teacher's work) on an object (e.g., a lesson plan) is often mediated by tools and/or artifacts (e.g., a template in a word processor). Further, this work is goal-oriented (e.g., the teacher wants to create a lesson that might help particular students learn about a topic). An activity – the most fundamental concept of

activity theory – may consist of one or more actions (e.g., to create a figure to be used in a task to be assigned to students), which are realized by operations (e.g., to draw a line). Frequently, actions are only meaningful in the social and cultural context of a shared work activity (e.g., a lesson plan is realized in anticipation of interaction with particular students in a particular classroom).

Activity theory developed from Russian psychology and has its origins in the 1920s and 1930s. Since the 1990s, international research communities, especially those interested in human-computer interaction, computer-supported cooperative work, and information systems, have valued its theoretical contributions. Many scholars (e.g., Bødker, 1991; Kaptelinin & Nardi, 2006; Nardi, 1996) have used activity theory as a conceptual tool to support interaction design (e.g., design of the user interface of software programs) in human-computer interaction. They have proposed practical guidelines for the design of interactive technology, based on a number of key principles of activity theory (Kaptelinin & Nardi, 2006). For example, based on what activity theorists refer to as the *internalization-externalization* principle – the notion that "activities include both internal (mental) and external components which can transform into each other" (Kaptelinin, Nardi, & Macaulay, 1999, p. 36), Kaptelinin and associates (1999) suggest that "computer systems should support both internalization of new ways of action and articulation of mental processes, when necessary, to facilitate problem solving and social coordination" (p. 36). This general guideline again is transformed into the practical design principle that a computer application should help the user avoid unnecessary learning, for example, to provide the user with a shortcut to do a complex task.

A number of scholars (e.g., Béguin & Rabardel, 2000; Rabardel, 1995; Rabardel & Verillon, 1995; Trouche, 2004) have, more recently, further developed activity theory to account for the dynamic, symbiotic relationship between the subject and the artifact. They have proposed a developmental theory of instrument-mediated activity – instrumentation theory. In addition to being grounded in activity theory, instrumentation theory also draws on an area of research about work activity analysis, which has developed from the work of Ombredane and Faverge (1955) and their successors (e.g., Wisner, 1995) in psychology and ergonomics in French speaking countries. These ergonomists focus on the analysis of human intelligence and inventiveness. Their studies suggested an important principle: individuals explore, interpret, and transform their goals as they cope with the artifacts and technical and organizational features of their environment (Weill-Fassina, Rabardel, Dubois, 1993). This principle, together with other principles of activity theory, provide foundation for the developmental theory of instrument-mediated activity.

A key contribution of Rabardel and associates' work is their introduction of the concept of *instrumental genesis*, which refers to the process through which an artifact is 'transformed' into an instrument when it is involved in object-oriented activity. According to the theory, an instrument consists of two components: (a) an artifact, either material or symbolic, and (b) one or more *utilization schemes* that are generated by the subject, through adaptation of pre-existing social schemes in interaction with the artifact. The instrument (artifact and utilization schemes) mediates interactions between the subject and the object of his or her object-oriented activity. Béguin and Rabardel (2000, p. 181) state: "The concept of instrumental genesis encompasses both the evolution of artifacts as the user's activity unfolds, and the building of utilization schemes, both of which participate in the emergence and development of an instrument." Both the incorporation of a new artifact into pre-existing utilization schemes (e.g., the use of the "save" function from a pre-existing authoring tool to a new authoring tool) and the construction, functioning, and enhancement of new utilization schemes to accommodate the new artifact (e.g., adapting older schemes from pre-existing tools such as those for layering graphical objects in tools like Microsoft PowerPoint ® to organize graphical content in a new classroom storyboarding tool) are subject-centered and key components of a process called *instrumentation*. The evolution or transformation of the artifact (e.g., its structure, operations), the *instrumentalization* process, is artifact-oriented. Through the instrumentalization process, the subject extends the intended use of the artifact on the basis of its inherent attributes (e.g., the subject can use the facilities of Google Documents to do a presentation). Instrumentation and instrumentalization are the two complementary, inseparable sub-processes of an instrumental genesis that contribute to the construction and evolution of an instrument.

Researchers who are interested in the developmental theory of instrument-mediated activity described above have provided approaches for the design of instruments. For example, on the basis of scheme-based design, Béguin and Rabardel (2000) emphasized the value of understanding the subject's assimilation and accommodation of utilization schemes in the process of introducing and evaluating a new artifact. On the basis of instrumentalization-supported design, they recommend to build systems that are flexible in such a way that the subject can adapt to his or her needs easily, which is important because the subject's working environment is a dynamic system and his or her needs can change. To be able to realize such designs it is crucial to involve both the designer and the user in *instrumental co-genesis* processes over multiple design-

utilization cycles. This iterative design approach can provide an optimal way to understand users' developmental experiences and, therefore, to be able to develop a dynamic and flexible artifact that can properly address users' change of needs as well as difficulties of dealing with those needs (Rabardel, 1995; Béguin & Rabardel, 2000).

The design of complex systems that are based on information and communication technologies, such as online, practice-based learning environments, requires many design-utilization cycles, which require a long-term commitment from both designers and users. This requirement would be a challenge for researchers to conduct extensive studies about instrumental co-genesis processes. In the following section, we summarize the history of the development of Lesson*Sketch* over seven years, and we explain why Lesson*Sketch* provides a valuable context for research on instrumental co-genesis.

The Development of Lesson*Sketch*: An Online Platform for Practice-Based Teacher Education

Lesson*Sketch* has been designed and produced by Herbst, Chazan, and Chieu, with the support of grants from the National Science Foundation to the first two authors. In earlier projects, Herbst, Chazan, and their colleagues succeeded in using animations of classroom scenarios of cartoon characters to stimulate groups of practicing teachers to discuss their professional practice (Herbst & Chazan, 2003; Herbst, Nachlieli, & Chazan, 2011). As a follow-up of that work, our research group created online experiences for teacher development: An online experience is a set of activities that engage teachers individually or in virtual groups in navigating, annotating, and discussing the work of teaching as represented in media streamed online. The first version of Lesson*Sketch* was born in that context and was relatively simple. The experiences were simple, isolated sequences of webpages deployed on a learning content management system (ATutor, www.atutor.ca), where users could watch animation clips, respond to open-ended questions, and interact with others in a discussion forum.

The current version of Lesson*Sketch* is complex and addresses the needs of different kinds of users, including pre-service teachers, in-service teachers, teacher educators, professional developers, and educational researchers. Figure 1 shows a multimedia-based discussion forum in the current version of Lesson*Sketch*.

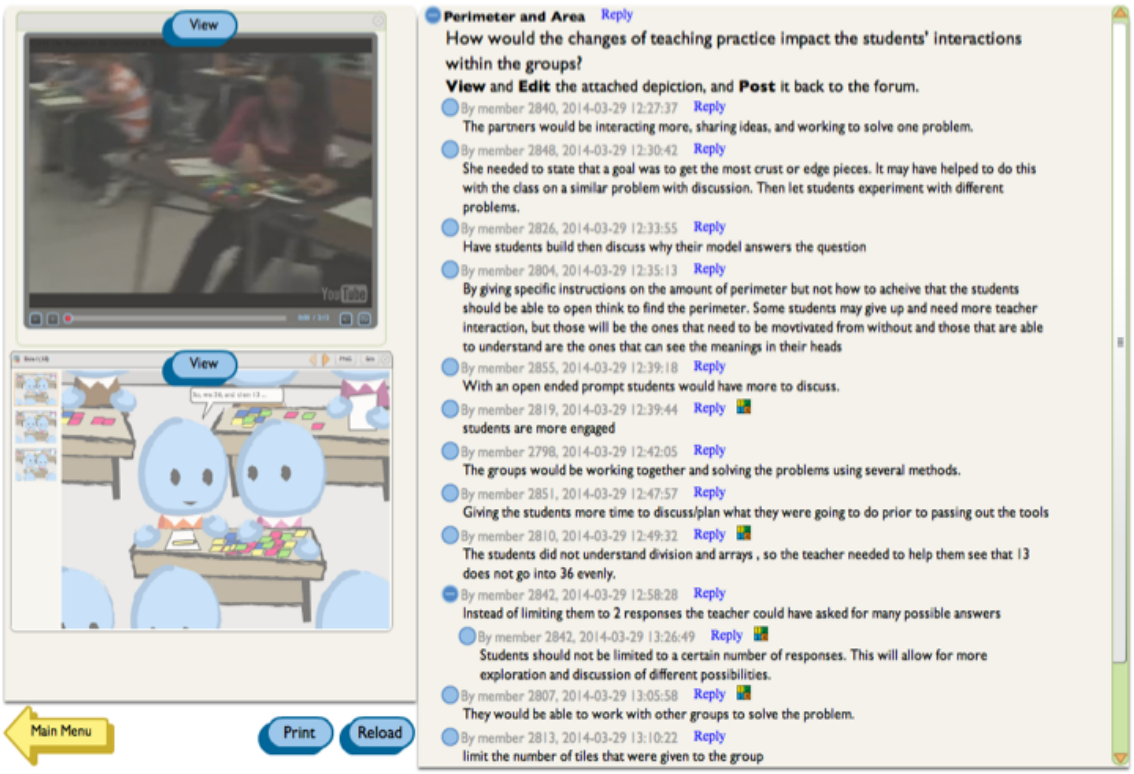

Figure 1. Screenshot of a multimedia-based forum in the current version of Lesson*Sketch*.

Note. User's name is replaced with a system-generated ID to protect identity.

We have also applied principles from practice-based teacher education to improve Lesson*Sketch*. By practice-based teacher education, we mean the concept of learning teaching *in*, *from*, and *for* practice as proposed by Lampert (2010).

Learning teaching *in* practice means that learning activities are situated in the work of teaching. Learning teaching *from* practice means that the practice of teaching is a primary object of the study. Learning teaching *for* practice means that the main goal of learning activities is to enable the work of teaching. Regarding those three aspects of practice-based teacher education, we address three critical goals: (a) to support the use and creation of representations of the work of teaching through classroom stories, (b) to support the study of representations of practice, and (c) to support the discussion of representations of practice. For the first problem, we support the use of cartoon characters to create classroom stories in the forms of animations or storyboards (we have provided collections of those animations and storyboards in advance for users, but they can create their own storyboards). Lesson*Sketch* members can use video records of teaching (e.g., hosted in YouTube), as well. The use of nondescript cartoon characters can help the viewer focus on practice rather than on unimportant characteristics of individuals or classroom settings (Herbst, Chazan, Chen, Chieu, and Weiss, 2011). We built **Depict**, a cartoon-based storyboarding tool, and **Inscribe**, a whiteboard content (including diagrams) editor, to help users create and edit classroom stories (see Herbst & Chieu, 2011). For the second problem, we built **Annotate**, a media annotation tool, to support the study of practice. For example, **Annotate** supports users in watching a video clip, making selections from those clips, and making time-stamped comments at specific moments or tied to specific selections. For the third problem, we created **Discuss**, an asynchronous communication and collaboration tool, to sustain the creation of alternative practices and conversations around practices represented in classroom stories (e.g., see Figure 1). Unlike the first version, the current version of Lesson*Sketch* also provides **Plan**, a multimedia authoring tool used along with the tools described above, and **Manage**, an experience management tool, to help teacher educators create and deliver online experiences to their clients.

There have been many substantial changes in the design of Lesson*Sketch* from its first version to its current version. An important note is that many times members had not recognized what they would need for their work until they used and interacted with Lesson*Sketch* for an extensive period of time. In the following sections, we show how the instrumental co-genesis approach described earlier can help to guide the technology development of Lesson*Sketch*, and we present design principles that we have learned so far.

Research Design

Research Questions

The main goal of this study is to describe the development of Lesson*Sketch* as an instrumental co-genesis through which features of the software were developed in response to users' needs and difficulties, in order to demonstrate the value of adopting this perspective on the design of software. We demonstrate that value by listing some of the design principles that we have been able to derive from our work, as a consequence of adopting that perspective. This study therefore offers responses to the following two research questions:

1. What are the changes that have occurred in Lesson*Sketch*'s design and in the ways that its users and developers conceptualize its use (i.e., the characteristics of the instrumentation and instrumentalization processes), over the years, in response to the needs of the users?
2. What principles for the development of online, practiced-based learning environments have we been able to derive, by adopting an instrumental co-genesis approach to the design of Lesson*Sketch*?

Settings, Participants, and Procedure

We conceptualize Lesson*Sketch*'s user community as comprised of three main sub-groups. The first is our research team, which includes about 10 researchers in mathematics education. Our principal use of the software has been for research, but we have also used it in our teaching. Since its development, in light of those uses, we have regularly discussed the affordances and limitations of each of its key features and the software has been developed further to address some of those limitations.

The second group consists of mathematics teacher educators, working at various institutions. Since early components of Lesson*Sketch* were first developed, teacher educators have asked us to help them create online experiences for their students. Still envisioning Lesson*Sketch* as a tool that is particularly well-suited for teacher education, we recently acquired a grant to support the creation of rich media materials for initial mathematics teacher education, and recruited twelve mathematics teacher educators to be Lesson*Sketch* Research and Development Fellows: working at ten different institutions, to create online experiences for their teacher candidates. Interaction with these fellows has provided us with

useful information about the needs of this portion of our user community. We have offered all of the teacher educators that we have worked with technical support through email, as well as through telephone and face-to-face conversations. We have also been conducting regularly scheduled videoconferences with them, in order to stay abreast of their needs and the difficulties that they are experiencing. The third group consists of the preservice and in-service teachers who have participated in our research studies, sometimes from their own location and other times in a computer laboratory at our University, and the preservice and in-service teachers that have participated respectively of teacher education or professional development interventions. We have observed these users in the laboratory and also given them index cards, in which we have asked them to take notes about (a) things that happened that they did not intend to happen, (b) problems that required technical support, and (c) problems that they resolved without technical support. For participants working online from remote locations, we have provided hotline access as well as an email help line.

In both online and face-to-face sessions, we have asked users to complete technology surveys about their experience with Lesson*Sketch*. In face-to-face sessions, we have collected screencasts of selected users to capture their interaction with the computer they were using.

Data Sources and Data Analysis

Lesson*Sketch* stores all of the artifacts (e.g., storyboards) created by each member, teachers' responses to questions in online experiences, all users' forum posts, all users' interactions with media (e.g., what animations they watched, which events of the animations the commented on and what those comments were), and other basic analytics data (e.g., timestamps of all users' login and logout, time spent on each activity in an online experience). As stated above, for different groups of selected users, we collect their technology surveys and index cards, observation notes, and screencasts of their interaction with Lesson*Sketch*. For the group of selected teacher educators, we collect video records of their group meetings at workshops and have had those records transcribed. We also archived all discussion threads about technical support via email. In addition, for the first group of members (our research team), notes, a feature 'wish-list', bug reports, memos that specify revisions or new features with explanation of why a revision or a new feature would be needed were archived electronically.

In earlier studies, we already applied different coding schemes (see Chieu, Herbst, & Weiss, 2011; Chieu, Kosko, & Herbst, 2015) to analyze part of the dataset and learn about how Lesson*Sketch* supported teachers' conversations about their professional practice. In this study, we look more into the data described above to understand how we, as designers of Leson*Sketch*, have addressed users' change of needs and their difficulties of the use of Lesson*Sketch* over time.

Results and Discussion

The dataset above have provided numerous case studies that can be used to address the research questions stated above. Because of limited space, we focus on four cases: from face-to-face study groups to online experiences, from consumer to producer of representations of practice, from viewer to analyst of representations of practice, and from consumer to author of online experiences.

From Face-to-Face Study Groups to Online Experiences

This case study was in a context where we replicated some successful features of face-to-face study groups (e.g., watching animated classroom stories collectively with one or two moderators, spotting critical events, and discussing those events) to build online experiences. In transitioning to the online context, we still conceived these as group experiences, but used the affordances of the technology instrumentation to target two important goals. On the one hand we wanted to enable parallel and individually controlled access to the media by participants; on the other hand we wanted to have access to individual thoughts about the media, in addition to records of their participation in a collective conversation. Online conversations could happen in two different ways - through forum and chat - providing different conditions to examine the quality of talk about practice. The conversations in both synchronous chat rooms and asynchronous forums for both groups of preservice teachers and groups of in-service teachers were highly interactive and meaningful (Chieu & Herbst, 2011). We were able to identify a number of principles (Chieu, Herbst, & Weiss, 2011) for the design of tools to mediate professional conversations, for example: (a) to embed animated classroom stories into the virtual discussion space to help users focus on conversation about teaching practices, (b) to enable users to have full control over the video player so that they can refer to fine-grained practices represented in the animations, and (c) to have one or more moderators to organize and stimulate discussion threads. The following comment from a user demonstrates the value of this design:

> "I really like being able to look at a specific spot in the film without making everyone else look at the same spot. In the [face-to-face] sessions I was often not interested in the same spot of video that others were." (Chieu, Herbst, & Weiss, 2011, p. 21).

We also learned that, although preservice teachers seemed to find the forum easy to use, they seemed to lack the utilization schemes necessary to handle the highly interactive and multi-threaded nature of the chat condition. In contrast, in-service teachers worked well in both conditions. We imagine that this might be due to their pre-existing schemes for orchestrating classroom management (e.g., how to handle interactive and multi-threaded nature of classroom interaction) into the instrumentation process, while they were making conversations in chat. Those observations suggested that forum would work well for both groups of user and thus informed us to focus on the improvement of the design of forums in the next design cycles. For example, as a number of users claimed that the organization of forum posts was confusing we used a tree-based organization of forum posts to address that problem.

Another valuable finding from the analysis of users' conversations was that they frequently proposed alternative teaching actions while they watched, studied, or discussed animated classroom stories. But it was difficult for them to describe alternative practices in detail using text only. There seemed to be a need for a graphical language to represent what they tried to say. This suggested to us that it would be important to give our end users control of an authoring tool that thus far had only been used by the design team to screenplay animations. The **Depict** tool (Herbst & Chieu, 2011) provided end users the control of graphical affordances that complemented the resources from print in enabling users to narrate scenarios. The design principle here is *to build graphical authoring tools that can support learners in representing their professional practice as storyboards*.

From Consumer to Producer of Representations of Practice

As noted above, initially, end users could narrate their classroom experiences and propose alternatives using text, and the phasing in of **Depict** enabled them to author scenarios in the form of storyboards. A key component of this instrumentalization was the introduction of **Inscribe,** a drawing tool we adapted to help users create board content such as diagrams and that we enabled to produce content that could be used inside **Depict** to support users in creating classroom storyboards in which a cast of cartoon characters was used to enact the roles of teacher and students. In **Depict**, people can use drag-and-drop functionalities and a graphics library of classroom settings, cartoon characters, furniture, supplies, and dialogs to build frames of classroom stories. Users have created thousands of classroom stories in the form of cartoon-based storyboards. An empirical study (Chen, 2012) indicated that **Depict** is better than oral narration in supporting preservice teachers when they anticipate the teaching of a lesson they had already planned.

The phasing in of **Depict** into Lesson*Sketch* was initially designed to enable participants of online experiences to attach representations of alternative practices to their forum postings about a piece of media they had watched. But over time all kinds of users have extended the use of **Depict**. For example, although we have provided a collection of animated classroom stories that could be used in online experiences, these have not always been enough for teacher educators and they have used **Depict** to create their own stories. We have also used **Depict** to create another collection of classroom stories to augment our collection of animations and even included subjects other than mathematics. As those uses increase they called for further instrumentalization processes that did require us several design cycles to improve **Depict**; the current version is a complex tool with many features. A design principle here is *to balance between time spent to create a representation of practice and the level at which the tool allows for the customization of a representation*, so that users can create a story quickly but still be able to give crucial details, for example, for classroom settings, characters' expressions, and character interactions (see also Herbst et al., 2011). Along those lines, the current graphics set allows the representation of many different classrooms (elementary, secondary, math, science, language, social studies, seating in rows, in groups, and even on the floor), yet the graphics do not support detailed design of individual characters. This permits the representation of practice in context without taxing the creation time too much or making the end products too distinct. This design principle has been supported by users' comments on how easy it is to use **Depict** and on the quality of classroom stories they created using the tool. Here are a couple of comments by preservice teachers on the usefulness of the tool:

> "...the use of the comic was helpful because it focused entirely on the actions and dialogue happening within the classroom more so than [sic] a description of the agenda for the class. It really pushed me to think ahead to the interactions students would have with the teacher, the content and each other."

> "One of my most favorite activities I have engaged in this course that I find helpful are the focal practice comic representations. These comic representations help me become more aware of how students would learn better or not better before I conduct my lessons. In a way, the comic representations help me see things from the point of view of the students. I would say the activity allows me to become more aware of what effective instructional practices I am already utilizing and what I should implement."

Another principle here is *to consider flexibility in the design of the tool to be able to accommodate various needs by users*, which is consistent with a principle that Béguin and Rabardel (2000, p. 184) have proposed: "One way of handling the instrumentalization process that comes to mind is to propose flexible systems that users can adapt to their needs." For example, over time we have added various options that enable users to customize key features of a representation of teaching such as classroom settings, characters' appearance and interaction, and views of classroom (e.g., zoom in and zoom out).

In addition, a lesson we learned from instrumental co-genesis processes of **Depict** is that after interacting with this tool for a long period of time some users have brought up the need to give comments on each frame of the story, for example to indicate intentions or goals or to describe generally events that take too long to narrate frame by frame and are unnecessary to the main story. They could instrument those goals by using the caption feature to add comments at the bottom of each frame, but this may only take care of some of those needs. The extended use of the caption box would not be desirable if the same story was to be used in multiple contexts: for example a story created by a teacher educator to illustrate a technique could use his annotations of the technique when somebody else is sifting through material to teach a course, but might have no need for such commentary when the material is actually shown to students. Thus we realized the need for separate ways of including comments and designed for this purpose both a story layer (classroom observers in the edges of the storyboard frame can have a dialogue about the action and this dialogue can be included or excluded in versions of the story) and a new tool – **Annotate**. The design of **Annotate**, which is presented in the next section, helped address the need for other sorts of commentary. The design principle here is *to identify objectives of mediation clearly and build a separate tool for each objective*.

Another development was that a number of groups extended the use of **Depict** and **Discuss** to co-create storyboards in an asynchronous mode. For example, a member initiated a discussion thread in a forum and attached a first version of a storyboard. Another member joined the discussion thread, edited the first version, and re-attached it to the forum thread. They continued to do so until all members approved the final version. Since they worked on the same storyboard asynchronously, they created a rule that each member took their turn to edit the current version and re-attach the new version in the discussion thread, and they used email to negotiate that division of labor. The observation of this instrumentation process informed about specific needs and prompted us to think about how technologies should be designed to support asynchronous collaboration. For example, we observed that there is a need for more than one member to work on the same version of a storyboard at the same time, and subsequently there is a need to merge their work to create a collective version and another need to resolve any conflicts that can happen during the merging process (e.g., they all edit the same dialog in the same frame of the story). This "version control" issue is common across collaborative work in document authoring and software development. We have not dealt with those needs yet in Lesson*Sketch*, but the presence of users' ad hoc solutions indicates that this is a user need, hence an area in which Lesson*Sketch* could use improvement. In the context of design for asynchronous collaboration, the following principles are useful: (a) *to enable different members to work on a version at the same time*, (b) *to enable members to merge their work*, and (c) *to enable members to resolve any conflicts that can happen in the merging*.

There have been many examples that show difficulties that the users encountered while working with Lesson*Sketch*. Because of limited space, we showed here a couple of common difficulties. Many users had difficulty of publishing a storyboard in the form of a slideshow (i.e., a set of images) before they could attach it to a response or a forum post, because although they knew the "save" function in many authoring tools they hadn't had any pre-existing utilization schemes related to the "publish" function. Note here that **Depict** generates two kinds of documents: A depiction is an editable storyboard which is generated incrementally and kept in the user's cloud resource space for future use after the use of "save" but that can only be accessed using **Depict**; in contrast, a published depiction is a rendered storyboard that can be embedded and played within **Annotate** files or in **Experiences**. Some users figured out the need to publish a depiction after a while but could only internalize it after several attempts. Some other users needed technical support to be able to do it.

Similarly, many users, including some experienced ones, had difficulty when they wanted to edit a storyboard in a forum thread and post it back to the forum thread, because there were so many steps involved in that task. So, although people can construct new, simple utilization schemes to accommodate the new artifact many of them would struggle, or at least feel uncomfortable, with complex utilization schemes, especially those that include a significant number of unintuitive steps. We handled this problem by cutting the number of steps and adding a contextual, intuitive prompt in large font, right below the story editing canvas. This enhancement helped inasmuch as we haven't had complaints about this problem again. For example, we used the prompt "Post this storyboard back to the forum" in the context of editing a storyboard in forum. The user then can click the "Post" link to tell the system to publish the storyboard and attach the published version to the forum. The design principle here is *to provide shortcuts for complex utilization schemes*. This principle is an operational realization of a principle in activity theory about avoiding unnecessary learning (Kaptelinin, Nardi, & Macaulay, 1999).

From Viewer to Analyst of Representations of Practice

In face-to-face study groups, we observed a phenomenon that while watching animated classroom stories participants often asked the moderator to stop at interesting events and comment on them. In the first version of online experiences we noticed that some participants felt a little frustrated while watching a very long animation clip without any supporting tool. So, when we incorporated the collection of animations into Lesson*Sketch* we developed a feature that enabled users, while watching an animation, to stop at any point in the timeline of the video player and make time-stamped comments. That was a useful feature for participants to keep track of their animation annotations. Over time, more media (storyboards, images, whiteboard content, YouTube videos, and so forth) have been available and frequently used in online experiences. After an extensive period of interacting with those media, teacher educators and teachers asked for a similar annotation feature that could be used with different kinds of media. Hence, we improved Lesson*Sketch* so that teacher educators could enable their participants to annotate other kinds of media (e.g., in the case of storyboards users can give comments on each frame). Again, after another period of using those annotation tools it turned out that those tools were useful to support teachers in studying their professional practice, a key goal of practice-based learning described previously. The design principles here are: (a) *to build a tool that can support learners in studying fine-grained practices of their profession*, and (b) *the annotation tool should be designed flexibly to be able to accommodate different forms of media*.

Sometimes teacher educators and teachers wanted to reuse their annotations in different experiences but it was difficult because each annotation was associated to a specific annotation experience. They found a workaround (e.g., using copy and paste functions) but this solution was time consuming and error-prone. In addition, recent interviews with teacher educators revealed a need to annotate the same media collectively (they used Google Docs for text annotation but would want similar tools for video and storyboard annotations). Our awareness of those instrumentalizations informed how we built the **Annotate** tool to enable users to open a media file, annotate it, and save the annotation in an independent file in their resources, so that they could reuse it in any contexts that apply (e.g., to share it with other in forums or to attach it to a media annotation activity in an experience). A collective annotation mode is under development for Lesson*Sketch*. Again, the principles are: (a) *to design flexible tools that can adapt to users' change of needs*, and (b) *to identify mediation roles clearly and build a separate tool for each mediation role*.

From Customer to Author of Online Experiences

For the first two years of development of the Lesson*Sketch* platform, the software developer of our research team was the only member who could create and deliver multimedia online experiences. These were most often requested by teacher educators - our primary customers, at the time. Over time, there has been an increasing need of an authoring tool that enables teacher educators to build and deliver such experiences. At that time, this need seemed to be small and the potential complexity of multimedia experiences seemed not to justify the development of an authoring tool. When our user base generated larger demands we found it needed to dedicate efforts to an authoring tool that could generate the diversity of experiences that could be created with media. This is another example of situations where users' needs change as their interaction with the artifact unfolds.

We created **Plan** to help teacher educators author agendas (each agenda consists of a set of technology mediated activities) and **Manage** to help them deliver experiences to their clients. Both tools are complex and their development required many design cycles as well. The current version of **Plan** enables the author to drag and drop activity types (e.g., Media Show, Question, Discussion) on a canvas to create a workflow or agenda. Then, the author defines parameters for each activity type, for example, for Media Show they decide which media to include and how end users will interact with

media (e.g., whether they can annotate it or only view it). The current version of **Manage** enables the author to assemble agendas, to create a list of participants, to customize the navigation component, to send an invitation email to participants, and so forth. Recent interviews with teacher educators who are using Lesson*Sketch* for their classes have indicated that both tools are useful for them to build online, practice-based learning experiences for their preservice teachers.

There have been a number of examples of how the analysis of teacher educators' instrumentalization processes helped improve the development of both **Plan** and **Manage**. For instance, initially teacher educators used a word processing software to edit text before copying and pasting it into text boxes in **Plan**, because **Plan**'s text editor was very small and it didn't have a spellchecker. We then made **Plan**'s text editor larger (and a full screen mode for the text editor is under development) and we incorporated a spellchecker into it. Similarly, since some teacher educators wanted their students to be able to go back to previous screens inside an experience while some teacher educators only wanted their students to move forward, we addressed this conflicting needs by adding a navigation option in **Manage** so that authors could turn on or off the back button inside an experience. The design principle here is *to understand variations of users' needs and design flexible tools that can adapt to that variety*.

Conclusion

In this paper, we describe and explain how the instrumental co-genesis approach is useful to analyze and understand different kinds of users' developmental experiences while interacting with different versions of Lesson*Sketch*, an online practice-based learning environment for teacher education. The understanding of users' instrumentation and instrumentalization processes through multiple design cycles of Lesson*Sketch* has helped us find a number of design principles (Table 1), and thus improve this product, making it become a successful learning environment to support practice-based teacher education. The analysis of a rich dataset collected, since 2008, has helped us understand that users' needs change over time because the environment around them develops, because their interaction with an artifact develops, and because sometimes they can only know what they need after interacting with an artifact for a while. The instrumental co-genesis approach has been, and continues to be, useful for the design and development of Lesson*Sketch*, and other complex learning environments, because it provides a useful framework to handle users' change of needs over time.

Table 1. Main design principles observed in the instrumental co-genesis of Lesson*Sketch*.

Goal of Practice-based Teacher Education	**Design Guidelines**
To support the use and creation of representations of practice through classroom stories.	● To build graphical authoring tools that can support learners in representing their professional practice as storyboards. ● To balance between time spent to create a representation of practice and the level at which the tool allows for the customization of a representation.
To support the study of representations of practice	● To support learners in studying fine-grained practices of teaching.
To support the discussion of representations of practice	● To enable different members to work on a version at the same time. ● To enable members to merge their work. ● To enable members to resolve any conflicts that can happen in the merging. ● Other principles are documented in earlier studies (Chieu et al., 2011, 2015).
All goals	● To consider flexibility in the design of tools to be able to accommodate various needs by users as well as to adapt to users' change of needs. ● To identify objectives of mediation clearly and build a separate tool for each objective. ● To provide shortcuts for complex utilization schemes.

Endnotes

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