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Tracing the development of teacher knowledge in a design seminar: Integrating content, pedagogy and technology

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Abstract

Effective technology integration for teaching subject matter requires knowledge not just of content, technology and pedagogy, but also of their relationship to each other. Building on Schulman's [Schulman, L. S. (1987). Knowledge and teaching: foundations for a new reform. *Harvard Educational Review, 57*(1), 1–22] concept of pedagogical content knowledge, we introduce a framework for conceptualizing *Technological Pedagogical Content Knowledge*—TPCK [Mishra, P., Koehler, M.J., (in press). Technological pedagogical content knowledge: A new framework for teacher knowledge. Teachers College Record]. We report the results of a semester-long investigation of the development of TPCK during a faculty development design seminar, whereby faculty members worked together with masters students to develop online courses. Quantitative discourse analysis of 15 weeks of field notes for two of the design teams show participants moved from considering technology, pedagogy and content as being independent constructs towards a richer conception that emphasized connections among the three knowledge bases. Our analyses suggests that developing TPCK is a multigenerational process, involving the development of deeper understandings of the complex web of relationships between content, pedagogy and technology and the contexts in which they function. Pedagogic, pragmatic, theoretical, and methodological contributions are discussed.

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1. Introduction

The issue of what teachers need to know about technology for effective teaching has been the center of intense debate in the recent past (e.g., Handler & Strudler, 1997; National Council for Accreditation of Teacher Education, 1997; U.S. Congress Office of Technology Assessment, 1995; U.S. Department of Education, 2000; Zhao, 2003; Zhao & Conway, 2001). There is, however, little clarity about what form this technological knowledge should take, how it should be represented, measured, or reported. Most scholars working in this area agree that traditional methods of technology training for teachers—mainly workshops and courses, are ill-suited to produce the "deep understanding" that can assist teachers in becoming intelligent users of technology for pedagogy (Brand, 1997; Milken Exchange on Education Technology, 1999; U.S. Department of Education, 1999). A survey by Milken Family Foundation and ISTE found that teacher-training programs, in general, do not provide future teachers with the kinds of experiences necessary to prepare them to use technology effectively in their classrooms. Specifically, they found that formal stand-alone IT coursework does not correlate well with technology skills and the ability to integrate technology into teaching.

A review of the recent teacher education research around technology will show numerous examples of teacher education programs that have implemented instructional technology in ways that encourage integration (for examples see, Fulton, Glenn, Valdez, & Blomeyer, 2002; Fulton, Glenn, & Valdez, 2003; Hacker & Niederhauser, 2000; Loucks-Horsley, Hewson, Love, & Stiles, 1997; Niederhauser, Salem, & Fields, 1999; Niederhauser & Stoddart, 2001; Strudler & Wetzel, 1999). Most of these approaches have involved providing teachers and teacher candidates with experiences with real educational problems to be solved by technology.

Our work with in-service teachers reported in this paper falls into this tradition of involving teachers in authentic problem solving with technology. Over the past few years we have been involved in a design experiment (Design-Based Research Collective, 2003) to develop a framework that captures some of the essential qualities of teacher knowledge required for technology integration in pedagogy. We argue that intelligent pedagogical uses of technology require the development of a complex, situated form of knowledge we call Technological Pedagogical Content Knowledge (TPCK). At the heart of TPCK is the dynamic, transactional relationship between content, pedagogy and technology. Good teaching with technology requires understanding the mutually reinforcing relationships between all three elements taken together to develop appropriate, context specific strategies and representations.

This paper describes our efforts on developing TPCK as a group of educators participated in a design seminar where they worked collaboratively in small groups to develop technological solutions to authentic pedagogical problems (Mishra & Koehler, 2003). We describe the process by which teachers built something that was sensitive to the subject matter (instead of learning the technology in general) and the specific instructional goals (instead of general ones). In particular we develop representations of the evolving nature of TPCK through attention to *design talk,* i.e. the kinds of conversations that occur in design teams as they struggle with authentic problems of technology integration in pedagogy.

Prior to describing our research study we offer an introduction to the theoretical and conceptual foundations of the TPCK framework as well as a description of the *learning technology by design* process.

2. Introducing technological pedagogical content knowledge (TPCK)

There's more to teacher preparation and faculty development than training teachers how to use tools – it requires appreciation of the complex set of interrelationships between artifacts, users, tools and practices. In particular, it requires teachers to become sensitive to the demands of harnessing and integrating technology, pedagogy and content. We argue, as do others, that knowledge of technology cannot be treated as context-free, and that good teaching requires an understanding of how technology relates to the pedagogy and content (Hughes, 2005; Keating & Evans, 2001; Lundeberg, Bergland, Klyczek, & Hoffman, 2003; Margerum-Leys & Marx, 2002; Zhao, 2003). In this view, technology is treated as a knowledge system (Hickman, 1990) that is neither neutral nor unbiased. Rather, technology has its own propensities, biases, and inherent attributes (Bromley, 1998; Bruce, 1993) that make some applications more suitable for certain tasks than others. Thus, technology cannot be treated as a knowledge base unrelated and separate from knowledge about teaching tasks and contexts – it is not only about what technology can do, but also, and perhaps more importantly, what technology can do for them as teachers. Specifically, we advocate increased attention to the complex interplay between *Technology, Content, and Pedagogy* (Koehler, Mishra, Hershey, & Peruski, 2004; Mishra & Koehler, in press). In our framework, we have built upon Schulman's (1986, 1987) work describing Pedagogical Content Knowledge, to highlight the importance of *Technological Pedagogical Content Knowledge* (TPCK) for understanding effective teaching with technology (see Mishra and Koehler, in press for a more complete discussion of these issues).

At the core of our framework (see Fig. 1), there are three areas of knowledge: Content, Pedagogy and Technology.

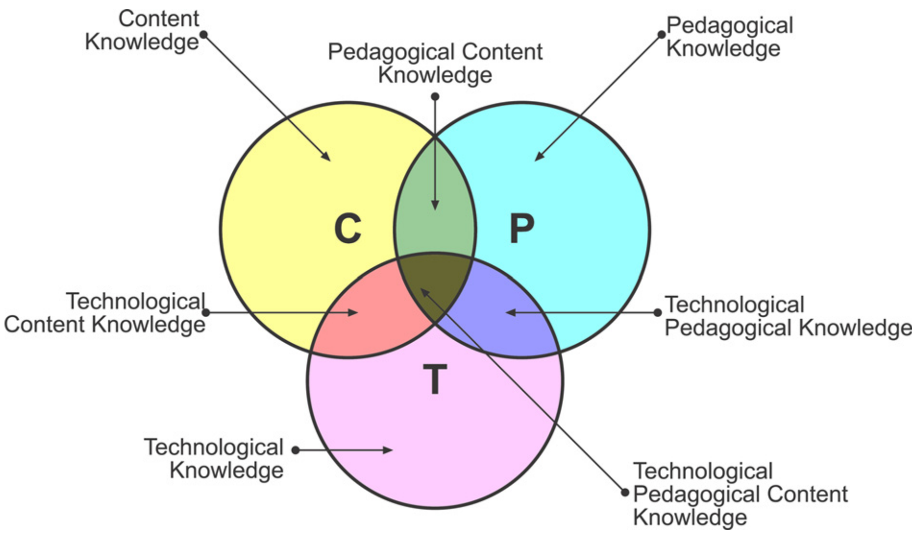

Fig. 1. Pedagogical technological content knowledge.

Content (C), is the subject matter that is to be learned/taught. The content to be covered in high-school social studies or algebra is very different from the content to be covered in a graduate course on computer science or art history.

Technology (T), broadly encompasses standard technologies such as books and chalk and blackboard, as well as more advanced technologies such as the Internet and digital video, and the different modalities they provide for representing information.

Pedagogy (P), includes the process and practice or methods of teaching and learning, including the purpose(s), values, techniques or methods used to teach, and strategies for evaluating student learning.

However, our approach goes beyond seeing C, P, and T as being useful constructs in and of themselves. Our approach emphasizes the connections and interactions *between* these three elements. For instance, a consideration of P and C together results in *Pedagogical Content Knowledge*. This is similar to Schulman's (1987) idea of knowledge of pedagogy that is applicable to the teaching of specific content. This would include representation and formulation of concepts, pedagogical techniques, knowledge of what makes concepts difficult or easy to learn, knowledge of students' prior knowledge and theories of epistemology. This knowledge differs from that of a disciplinary expert and from the general pedagogical knowledge shared by teachers across disciplines.

Similarly, T and C taken together produces *Technological Content Knowledge*. This kind of knowledge involves understanding the manner in which technology and content are reciprocally related to each other. Technology often affords newer and more varied representations and greater flexibility in navigating across these representations. Teachers need to know not just the subject matter they teach but also the manner in which the subject matter is transformed by the application of technology.

A consideration of the overlap between T and P results in *Technological Pedagogical Knowledge.* This knowledge emphasizes the existence, components and capabilities of various technologies as they are used in teaching and learning settings. This might include an understanding that a range of tools exist for a particular task (e.g., fostering collaboration) as well as knowing what pedagogical strategies to employ to get the most out of a piece of technology.

Finally, a consideration of all three elements (T, P, and C) results in *Technological Pedagogical Content Knowledge (TPCK)*. We argue that technology integration in teaching and learning requires understanding the dynamic, transactional relationship between these three knowledge components (Bruce & Levin, 1997; Dewey & Bentley, 1949; Rosenblatt, 1978). In this view, good teaching with technology for a given content matter is complex and multi-dimensional. It requires understanding the representation and formulation of concepts using technologies; pedagogical techniques that utilize technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help address these issues; knowledge of students' prior knowledge and theories of epistemology; and an understanding of how technologies can be utilized to build on existing knowledge and to develop new or strengthen old epistemologies. Clearly this knowledge is different from and greater than that of a disciplinary expert (say a mathematician or a historian), a technology expert (a computer scientist) and a pedagogical expert (an experienced educator).

3. Implications for teachers learning technology

Viewing teachers' knowledge as including rich relationships between content, pedagogy, and technology, has significant implications for teacher education and teachers' professional development. Clearly, de-contextualized, didactic approaches that merely emphasize the acquiring of technology skills are unlikely to succeed, since they do not address difficult but crucial relationships between technology and content, and technology and pedagogy (Brand, 1997; Koehler & Mishra, 2005a; Milken Exchange on Education Technology, 1999; U.S. Department of Education, 1999; Mishra & Koehler, 2003).

The multifaceted nature of the TPCK framework would suggest the educational value of constructing learning environments where all three components are treated in an integrated manner, and not as separate knowledge bases. In order to foster teachers' understanding of these complex relationships, we have developed an alternative approach to develop teacher knowledge called *learning technology by design.* Philosophically and pragmatically, this approach is closely related to constructivist and project-based approaches such as learning-by-doing, problem-based learning, collaborative learning frameworks, and design-based learning. In each of these approaches, participants work collaboratively over extended periods of time to solve authentic problems. Many educators have long favored design-based approaches for a variety of reasons: Design approaches lend themselves to sustained inquiry and revision of ideas (Harel & Papert, 1990); they emphasize the value of complex, self-directed, and personally-motivated learning (Blumenfeld et al., 1991; Kafai, 1996); and they have been shown to lead to rich, meaningful learning in a variety of contexts, including the development of presentations, instructional software, simulations, publications, journals, and games (Carver, Lehrer, Connell, & Erickson, 1992; Kafai, 1995; Kafai & Resnick, 1996; Lehrer, 1991).

The *learning technology by design* approach extends these ideas to a consideration of authentic design problems for developing skillful teachers' reasoning about educational technology. In our semester-long seminars, teachers work collaboratively in small groups to develop technology-rich solutions to authentic pedagogical problems (Koehler & Mishra, 2005a; Mishra & Koehler, 2003), and accordingly, they learn about technology and pedagogy by actually using and designing educational technology to teach specific content. Because their explorations of technology are tied to their attempts to solve educational problems, we argue that, teachers using this method learn "how to learn" about technology and "how to think" about educational technology. In contrast to a standard workshop approach that puts teachers in the role of passive *consumers* of technology, the *learning technology by design* approach puts teachers in a more active role as *designers* of technology.

Most importantly, our approach provides opportunities for teachers to encounter the rich connections between technology, content, and pedagogy. Authentic tasks do not respect disciplinary boundaries and in fact bring the connections between the three elements to the forefront of learners' experiences. Moreover, the ill-structured nature of most authentic pedagogical problems ensures that there are multiple ways of interpreting and solving them. Thereby, teachers are more likely to encounter the complex and multiple ways in which technology, content, and pedagogy influence one another instead of thinking about rigid rules that imply simple cause-effect relationships between these components (Mishra, Spiro, & Feltovich, 1996).

4. Context for the research study

Over the past few years we have been involved in conducting research on the development of TPCK through participation in *learning technology by design* seminars. Thus the TPCK framework is not only helpful for articulating a clear approach to teaching (the *learning technology by design* framework), but also as an analytic lens for studying the development of teacher knowledge about technology.

In a previous publication (Koehler et al., 2004), we introduced the *learning technology by design* approach and presented a case study of a college faculty member (Dr. Shaker) as she worked with her design team to create an online course. Our analysis revealed important changes in Dr. Shaker's technological literacy and her thinking about her personal relationship with technology. In accounting for these changes, we hypothesized that the *learning technology by design* approach afforded rich opportunities for Dr. Shaker (and her other team members) to deeply consider the relationships between content, pedagogy, and technology (consistent with the TPCK framework).

Our most recent research work (Koehler & Mishra, 2005b) has focused on measuring the development of TPCK through surveys administered at different times during the semester. Our data clearly show that participants in our design teams moved from considering technology, pedagogy and content as being independent constructs towards a more transactional and co-dependent construction that indicated a sensitivity to the nuances of technology integration.

This study extends our work beyond the individual case studies and broad surveys. In particular, we are interested in better understanding the *manner* and *process* by which TPCK develops through participation in a design-based activity (neither of which was the focus of attention in our previous research studies). According to our arguments about the increased opportunities to develop integrated knowledge in the *learning technology by design* approach, we should see changes in the manner that groups think and talk about technology throughout the design process. Accordingly, we would expect that initial group discussions early in the design process would treat technology, content and pedagogy as being relatively independent realms of knowledge. However, with time, as participants work on design projects, we would expect the participants' conceptions to become more nuanced, recognizing the intertwined and complex relationship between these three components. In the present study, we are concerned with the following questions: Does learning during open-ended design activities actually lead to the development of more complex forms of knowledge? How does TPCK develop over time and through collaborative activity? How is design-talk in a *learning technology by design* seminar structured and what does it reveal about the development (if at all) of TPCK? How can the evolution of TPCK be represented, tracked and understood?

5. The study

We conducted this research within the context of a faculty development course taught by the first author. In this class, faculty members and graduate students worked collaboratively to develop online courses to be taught the following year. It is important to note that the design task (developing an online course) was an authentic one – the College of Education at our university began offering an online Masters degree program, and courses had to be developed for the program. However, most faculty members were not prepared to meet the demands of teaching and learning in an online environment, and the College began to seek ways to develop the faculty expertise in technology. One of the strategies chosen to address these challenges was to integrate faculty development into the already existing *learning technology by design* courses offered as a part of the Masters program in educational technology. Previously, these courses had teams of masters – only students working on authentic problems of design (e.g., design and redesign of a 5th grade website about the solar system). The addition of a faculty development component fit nicely, in that the design problems could be nicely refocused on the authentic projects brought by the faculty (the design of online courses).

This particular instantiation of the *learning technology by design* course included six faculty members and 18 students. The faculty and students met once a week for three hours in a computer lab. Students were assigned to groups led by individual faculty members. A typical class period included a whole-group component used to discuss readings and issues that applied to all groups, and a small-group component in which the design teams worked on their semester-long projects. In many ways, this design course was a typical graduate class experience for the participants – they read articles, discussed ideas, and were responsible for meeting course deadlines. However, there were some important differences. All the participants (faculty members and teachers alike) worked collaboratively on designing an online course. They were exposed to several technologies, assessed their usefulness, and included some of them in the design of their online class. The technologies used by the groups varied, depending on the content they were covering and the pedagogical decisions they made. One group, for instance, focused a great deal on researching potential ways for a faculty member to provide audio feedback to online students. Another group investigated the use of web-based PowerPoint presentations to offer overviews of the online lessons to be covered. Groups also explored a range of pedagogical issues relevant to the course they were designing, including techniques for developing online learning communities and strategies for incorporating problem-based learning in online settings. All of the groups learned about the principles of effective web design as well as issues related to copyright and privacy. This knowledge was shared with the larger class through whole-group discussions as well as through online critiques of work done by other groups. There were a few intermediary deadlines imposed by the instructor, but for the most part, the groups worked at their own pace to complete the design of the course by the end of the semester.

Clearly, the most important part of the class was the small group design work aimed at developing a prototype of an online course. The design task went beyond creating a website for the course and required the faculty members and students to work together to develop the syllabus, the course structure, the readings, student assignments, and assessment rubrics. They had to determine the nature of student interaction, how the course content would be offered and delivered, how technology would be used to accomplish course goals, and how the course website would be designed to make it both user-friendly and fit with course content and pedagogy.

5.1. Participants

Data for the study comes from close observations of two of the six groups of faculty and students in the class. The faculty members leading the groups had differing degrees of prior experience with technology (based on self-report), which could influence the nature of their learning and experience with the design course. For this reason, we selected one faculty member who had the greatest amount of experience with technology and another who had the least amount of experience. For instance, Dr. Jackson described herself as having ''been involved with educational technology for decades,'' while Dr. Adams, had limited knowledge and experience with technology and saw the course as ''an opportunity to explore new ways to think about course content while immersed in a rich context of thinking about technology.'' (All names are pseudonyms.)

Each of the professors was teamed up with students who were more or less of equal ability and interest in technology. Team formation was based primarily on student interest in the professor's project. Dr. Jackson's group (called *Jackrabbits*) had three student collaborators: Rahul, who had worked as a computer instructor in his home country and was currently an educational technology masters student; Hillary, a doctoral student in Family Ecology, had a ''high regard for the movement towards online, interactive technology''; and Andrew, a Masters student in educational technology, was ''excited to participate'' in this project. Dr. Adams' group (called *The Adams Family*) included graduate students Sandra, Mandy, and David. Sandra was a student in the Masters program and worked as a graphic designer at the university. Mandy and David were both teachers working on their Masters degrees.

5.2. Data collection

The third author, a doctoral student with extensive qualitative research experience was responsible for data collection (she was not involved in the teaching of the class). In order to separate the participants' coursework and grade from their role as a research participant the data collected for the study was not shared with the instructor (the first author) until after the course was complete and grades had been assigned. We collected four types of data: detailed notes taken from group discussions both in and out of class, e-mails between members of the groups, notes and other artifacts constructed by the groups, and self-progress surveys periodically taken throughout the semester.

The researcher observed and took detailed field-notes of the groups when they were involved in design related discussions. She divided her time relatively equally with each group, so that each group would be observed for at least part of each class meeting. The field notes were the primary focus of analysis with the other sources of data (surveys, email interaction etc.) serving a supportive role (i.e. corroboration or refutation of field note data). Thus the other data collected provided a broader context for the content analysis of the design talk as well as developing the case study of the two groups.

5.3. Data analysis

The primary methodology used for the analysis of the field note data was quantitative content analysis. Content analysis has been described as a ''research technique for the objective, systematic, quantitative description of the manifest content of communication'' (Berelson, 1952, p. 519). This definition allows for a variety of textual analyses that typically involves comparing, contrasting, and categorizing a set of data (Schwandt, 1997). Content analysis has been used for the analysis of a variety of data types such as audio, video recordings or transcripts of classroom discussions, interviews, observations, field notes and, more recently, computer mediated communications (Harasim, 1987; Iseke-Barnes, 1996; Levin, Kim, & Riel, 1990; Mason & Romiskowski, 1996; Mowrer, 1996). Content analysis can involve both numeric (quantitative) and interpretive data analyses (qualitative), or combinations of both. Content analysis has been most fruitfully used in going beyond the surface content of the transcripts towards the identification and analysis of latent variables (such as student understanding, higher order learning outcomes etc.). Though this does bring another layer of subjectivity to the process, this is outweighed by the ability of this methodology to make grounded inferences about more fundamental issues that are of greater research interest.

Once the researchers have a construct they wish to study (in this case the construct was TPCK) quantitative content analysis can be reduced to three essential steps (Riffe, Lacy, & Fico, 1998). First, the researchers identify representative samples of the communication they wish to study. This has often meant field notes or transcripts of classroom discussions (Flanders, 1970; Sinclair & Coulthard, 1975). In our case this involved the selection of design talk from the field notes. The second step involves creating a protocol for identifying and categorizing the target variable(s), and training coders to use this protocol. In our case this meant developing rubrics and protocols for the coding based on our prior theoretical description of TPCK, and our previous research (Koehler et al., 2004; Koehler & Mishra, 2005b). Third, after a transcript has been coded, the data is analyzed either to describe the target variable(s), or to identify relationships between variables. The use of both quantitative and qualitative measures is prompted by the goal of providing a more comprehensive picture of "design talk" in a *learning technology by design* seminar.

In keeping with the three-stage process outlined above, we began with selecting specific field notes for further analysis. The 15 weeks of notes were segmented into discourse episodes according to turns in the conversation. This segmentation into discourse episodes was done by consensus by the three researchers. Since we were interested in studying the development of TPCK over time as the participants worked on their design projects, we focused our analysis on a representative subset of the dataset. We did this by first splitting the 15 weeks of the semester into 5-week chunks to represent the beginning, middle and end of the semester (i.e. week 1–5, 6–10 and 11–15). We then chose one week from each of the chunks. In choosing the week we typically went with the chunk with the most amount of data. We thus ended up with 6 weeks: 3 weeks for each group, one each from the first, second and third chunk of the semester. These were: weeks 4, 10 and 15 for the Adams Family group and weeks 3, 8 and 15 for the Jackrabbits group.

The next step was the development of coding protocols consistent with the TPCK framework and then actually coding the data. The design episodes selected were coded based on the seven categories defined by the TPCK framework. The idea behind this was to see *what* was the focus of the conversations between the participants in the design teams. We began by categorizing each discourse episode as Technology (T), Content (C), or Pedagogy (P). Furthermore since the coding categories were not mutually exclusive, each discourse segment could be coded in multiple ways, such as a discourse segment could be coded as Pedagogy *and* Technology (PT), Content *and* Technology (CT), Content *and* Pedagogy (CP), or even Content *and* Pedagogy *and* Technology (TCP). Accordingly, the first two authors collaboratively analyzed and categorized each discourse episode from the six weeks of data (3 weeks each for two groups) as C, P, T, CP, CT, PT, or CPT. We also had three additional categories (group dynamics, social and miscellaneous) for coding the segments since not every group interaction was about technology, content or pedagogy.

However, since the focus of this paper is on the relationship between content, pedagogy and technology, we do not discuss the other categories any further. Table 1 lists examples for each of the categories used to code the segments. A complete transcript of the notes for the selected weeks and the codes assigned to each segment are provided in Koehler (2003). For reliability purposes, the data was re-coded by the same coders weeks later (four weeks for one group and eight weeks for the other) and overall agreement across the two coding intervals was 90%.

Once the data had been coded along these categories, we conducted a systematic quantitative analysis of the occurrence of particular categories (T, P, C, TP, TC, TPC and TPCK) to determine the nature and evolution of patterns of interaction as the groups were engaged in designing their

Table 1
Categories in the coding scheme with example corresponding note segments

Category	Example
Content (Coded as C)	(Week 15, Adams Family) Mandy: She then explained what she has done about the next unit – spanking vs. not spanking; giving candies vs. not giving candies, etc.
Pedagogy (Coded as P)	Week 15, David: I think they need something that can build teambuilding skill or something like that...since this is at the beginning.
Technology (Coded as T)	Week 10: David interrupted and suggested using dropdowns from chapter 1 for links to the various components in that chapter.
Miscellaneous (Coded as M)	Week 15: Sandra, "Mandy, can I copy your poem? It's so cute!"
Social (Coded as S)	Week 15: Dr. Adams told about the summer she spent in Switzerland and France and the tech course her husband taught and the tech things he did and how she was involved/not involved in it – the other three had lots of questions about the course DW taught in Europe...until Mandy brought the group back to room 128...
Group dynamics (Coded as G)	Week 4: Dr. Adams started the discussion by asking whether they should officially assign roles...
Content Pedagogy (Coded as CP)	Week 13: Dr. Adams then continued talking about the plans for the next weeks, "...the next chunk...about rewards...how do you use rewards for learning...the kinds of activities and the kinds of rewards...they would do this in their groups...or in the classroom or someone else's...have a lesson..."
Content Technology (Coded as CT)	Week 7: Mandy talked about (and showed printed pages) what she had found and been working on – materials on jigsaw learning and also some websites that she had found that they could use as links as well as get materials and ideas for their site – all on motivation.
Pedagogy Technology (Coded as PT)	Week 9: Sandra, "On the web...the students need to go to...what? We need to look at that now...where the students will click to get to that activity..."
Content Pedagogy Technology (Coded as CPT)	Week 9: Dr. Adams explained what the videotaping of Mandy's class is about and how it is related to "the package on 'interest' as a way of motivating students...think about how best I can deliver this to students...PowerPoint? Or what? So, we'll think about this together...another way is to audiotape to accompany the PowerPoint..."

online courses. We expected that the initial discussions would treat content, pedagogy, and technology as isolated concepts (in our coding scheme, we should see lots of T, C, and Ps, but relatively few CP, CT, PT, and TCP segments). However as the participants worked on their projects, we would expect the participants' conceptions to become more nuanced, recognizing the intertwined and mutually constitutive relationship between these three components (thus in our coding scheme, we would expect to find more CP, CT, PT, and TCP categories as the design project progressed). Analogous to these changes at the group level, we would expect to see some changes in the roles that individuals played in the projects. For instance, at the start of the design project, the faculty members would be regarded as content experts with some of the students being regarded as the technology experts. However, with time, there could be some change in the roles and assignments.

Thus, the quantitative and qualitative methods used in this study complement each other. While the quantitative method revealed broad patterns of design based discourse, the qualitative method facilitated local clarification through observation, description and interpretation of the features of interactions and the role of the faculty, students, and tasks.

6. Results

In the sections that follow, we present the results of data analysis separately for the Adams' Family design group and for the Jackrabbits design group. Although some findings are similar across the two groups, there are also important differences, which are considered in the following section.

6.1. *Results for the Adams' family group*

We represent the nature of design talk by tabulating the distribution of each of the coded categories over the selected weeks. Table 2 presents the percentage of coded segments over the early-, mid-, and late-week of the observations for each of the seven categories: Content-only (C); Pedagogical-only (P); Technology-only (T); Joint consideration of Content and Pedagogy (CP); Content and Technology (CT); Pedagogy and Technology (PT); and Content, Pedagogy, and Technology taken together (CPT); A statistical analyses of the data suggest that there are significant differences in the pattern of categories among the early, middle, and late week of the course (tested as Pearson's χ-Square: $X^2(12) = 31.03$, $p < .01$).

Table 2
Percentage of note segments assigned to each coding category for the Adams Family group

	C	P	T	CP	CT	PT	CPT
Early	3.8	3.8	38.5	3.8	0.0	26.9	0.0
Middle	8.3	20.8	8.3	25.0	0.0	10.4	0.0
Late	6.2	20.8	4.2	27.1	2.1	12.5	2.1

The rows do not total 100% because not all coding categories have been shown here.

Another representation of this data is provided in Fig. 2, which allows us to see some interesting changes in the topic of conversation as the course progressed. For instance looking at the second set of columns (for Pedagogy) we see that there was little talk about pedagogy in the early week. However, by the middle week talk about pedagogy shows a dramatic increase that persists into the later week of the course.

Also consider the shifting presence of technology in the discussion. The early week is dominated by technology, either in isolation or in combination with other terms. For instance T (taken singly) is 38.5% of the first week's data, and PT is another 26.9%. However, the middle and late weeks show a different pattern, in which technology is hardly ever talked about in isolation (T = 8.3% in the middle week, and T = 4.2% in the late week). Technology, if present in the conversation, is addressed jointly with pedagogy (PT = 10.4% in the middle week, and PT = 12.5% in the late week). Furthermore, the pattern established by the middle and late weeks is marked by an increased conversation around issues of content and segments that address content and pedagogy jointly. Finally, it is only in the last week that we see instances of CPT i.e. all three elements taken together.

In summary, Adams family discussions initially focused on technology and, at times, it's relationship to pedagogy. Somewhere during the middle of the course, however, technology ceased to be treated in isolation and was discussed mainly in relationship to pedagogy. Finally, issues of content and pedagogy (and their joint relationship) become the primary focus for this group. Most importantly, Fig. 2 shows a growing tendency for the group to discuss issues of content, pedagogy, and technology in relationship to one another (note the growth CP, CT, PT, and CPT over time).

The table of means (Table 2) and the graph of interaction (Fig. 2) offer insights into the overall patterns of discussion at the group level. However, these representations gloss over the dynamics

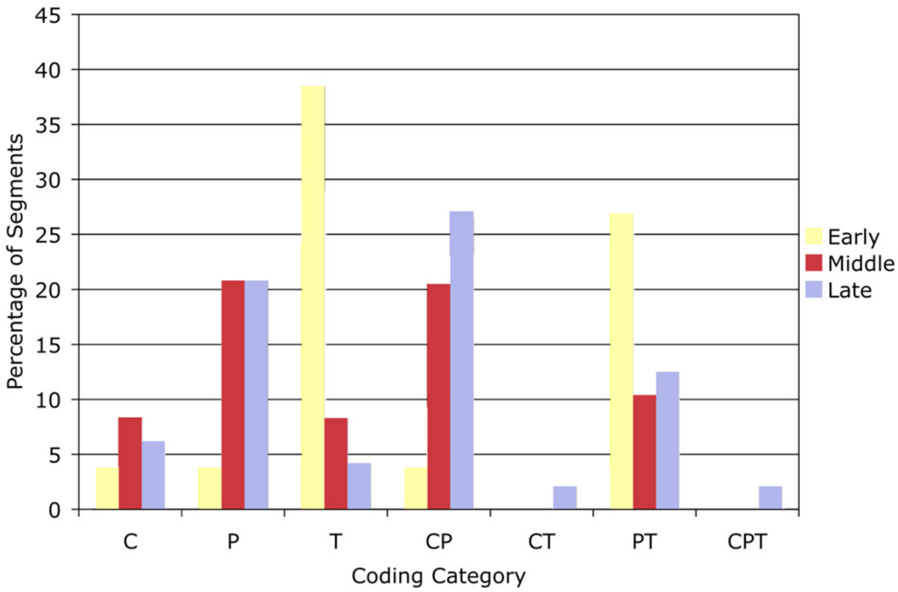

Fig. 2. Percentage of segments by category and week for Adams' Family group.

of the discussion and the roles that individuals played in raising ideas and developing the dialogue. In order to better the process of design talk and the contributions of individuals, we developed a representational scheme to graph the coded segments of each individual over time (see Fig. 3). Each box in the figure represents a segment from the transcript (the number across

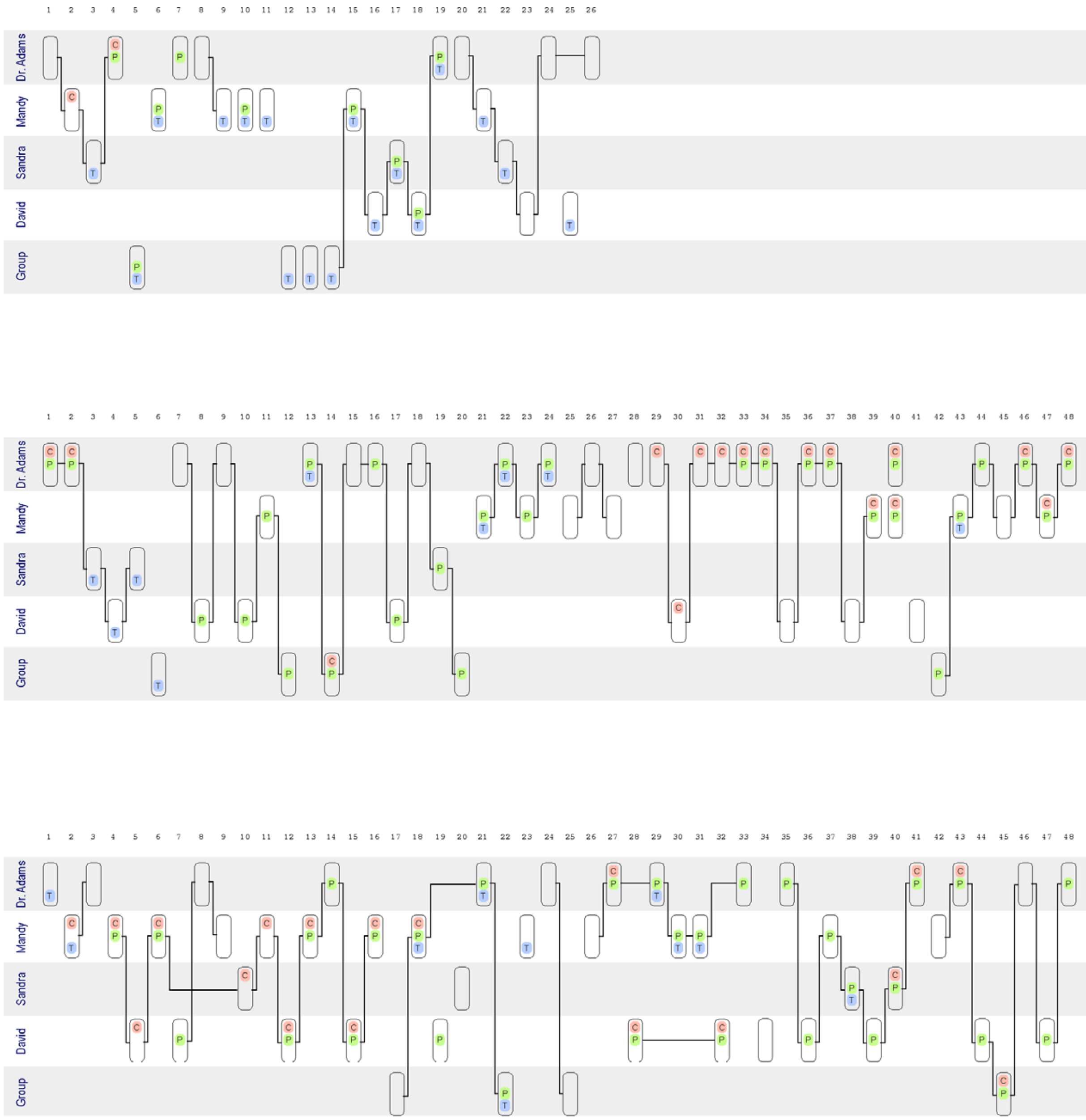

Fig. 3. Representation of the coded conversations for weeks 4, 10, and 15 of the course for Adams' Family. Line segments represent topical threads.

the top indicates the segment number), the letters inside the oval indicate the code assigned to the segment (C, P, T, CP, CT, PT, CPT or nothing), and lines connect the conversation threads. A thread is defined as a sequence of discourse segments that are on the same topic. An oval that is not connected to a prior segment indicates a new or unrelated topic.

There are several interesting qualities of the data evident in this graphical arrangement of the notes. First, there are changes in how conversations are started – in the early and middle weeks of the courses, conversations (threads) are initiated by Dr. Adams or by 'The Group'[2]. In contrast, by the week in the final third of the course, conversations are initiated by other group members.

Second, regardless of who initiates conversations, threads become longer and more sustained as the course progresses. The average length of the threads jumps from 2.1 in the early week to 4.3 and 3.4 in the middle and late weeks. For instance in the early week, 8 of the 12 threads consist of just one discourse segment and the longest thread consists of 6 segments. By the middle and later weeks we can see fewer isolated nodes and a greater number of extended threads (some are even up to 11 segments in length).

Third, there are changes in the extent to which topics are associated with individuals. That is, early in the course (and to a lesser extent during the middle of the course), certain topics of conversation are associated with particular individuals. For example, Dr. Adams seems to focus on issues of content, both in the early and middle weeks. The student members, on the other hand, seem to talk more about technology in the early weeks. However, this changes over time, such that in the late conversation, the segments related to content (C), pedagogy (P), and technology (T) are distributed quite evenly across the members of the group. In other words, these three components seem to be not only more integrated at a group level, but also within the individuals. Over time, each of the participants becomes more balanced in their design considerations, individually bringing elements of content, pedagogy, and technology to bear in their group conversations.

Fourth, Mandy seems to be the mediator through which the balance of content, pedagogy, and technology emerges. Early on, her contributions seemed to mitigate the content-heavy role of Dr. Adams and the technology-focused students. That is, her contributions from the start indicate more balance on these issues. Her role in the conversation also seems to be one of translator, serving to connect these two disjointed halves of conversation. An examination of the connecting threads (the lines in the figures) reveals Mandy's statements serve to connect the contributions of Dr. Adams (mostly devoted to content) and those of the other students in the group (mostly devoted to pedagogy and technology).

In summary, an analysis of the graphical arrangement of the conversations reveals a complementary picture to the group level analyses presented earlier. That is, content, pedagogy, and technology seem to (at least initially) exist in the conversation, but remain unconnected as the three topics reside in the separate contributions of individuals. Over time (with the help of Mandy), the individuals seem to mirror the group in that they have a more connected use of content, technology, and pedagogy as evidenced by what they bring to bear in a conversation.

[2] We suspect that the conversations that are labeled as being started by the 'Group' are in fact started by Dr. Adams, and that they are attributed to 'Group' as an artifact of the note-taking process. For instance, when the researcher summarizes a quick exchange, (e.g., "the group talked about good layouts"), the conversation was probably initiated by Dr. Adams.

6.2. Results for the Jackrabbits' group

An analysis of the categorical coding of notes for the Jackrabbits' group (Table 3 and Fig. 4) shows a considerably different pattern than observed for the Adams' Family Group (Table 2 and Fig. 2). The Jackrabbits exhibited a fairly stable pattern over time – conversations are dominated by technology (T, early 18.6%, middle 20.0%, and late 43.6%) and issues that intersect technology and pedagogy (PT, early 34.9%, middle 33.3%, late 20.5%). Although there is a change in the number of segments coded as Technology ('T'), a statistical analysis of the changes between the early, middle, and late week of the course indicates there are no significant differences (tested as Pearson's Chi-square: $\chi^2(12) = 16.38$, $p = .176$).

The diagrammatic mapping of the discussions (Fig. 5) also reveals some interesting patterns. Similar to the Adams Family Group, threads become longer and more sustained as the course progresses. For the Jackrabbits, the average length of the threads jumps from 1.9 in the early week to 3.0 and 3.25 in the middle and late weeks. For instance in the early-week, more than half of the segments consist of isolated topics (13 of the 22 total). By the middle and later weeks such isolated

Table 3
Percentage of note segments assigned to each coding category for the Jackrabbits group

	C	P	T	CP	CT	PT	CPT
Early	2.3	16.3	18.6	2.3	2.3	34.9	2.3
Middle	0.0	20.0	20.0	16.7	0.0	33.3	16.7
Late	5.1	7.7	43.6	2.6	0.0	20.5	2.6

The rows do not total 100% because not all coding categories have been shown here.

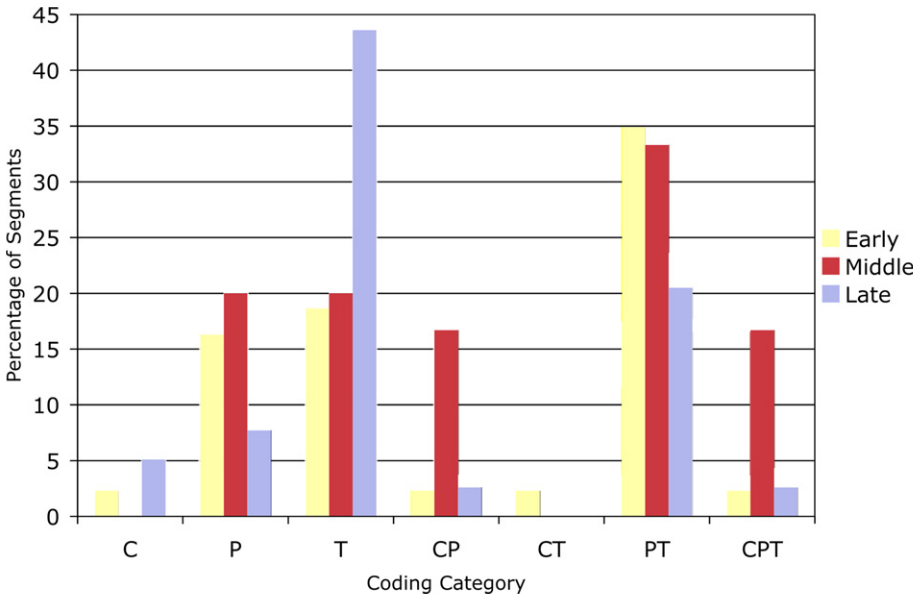

Fig. 4. Percentage of segments by category and week for Jackrabbits group.

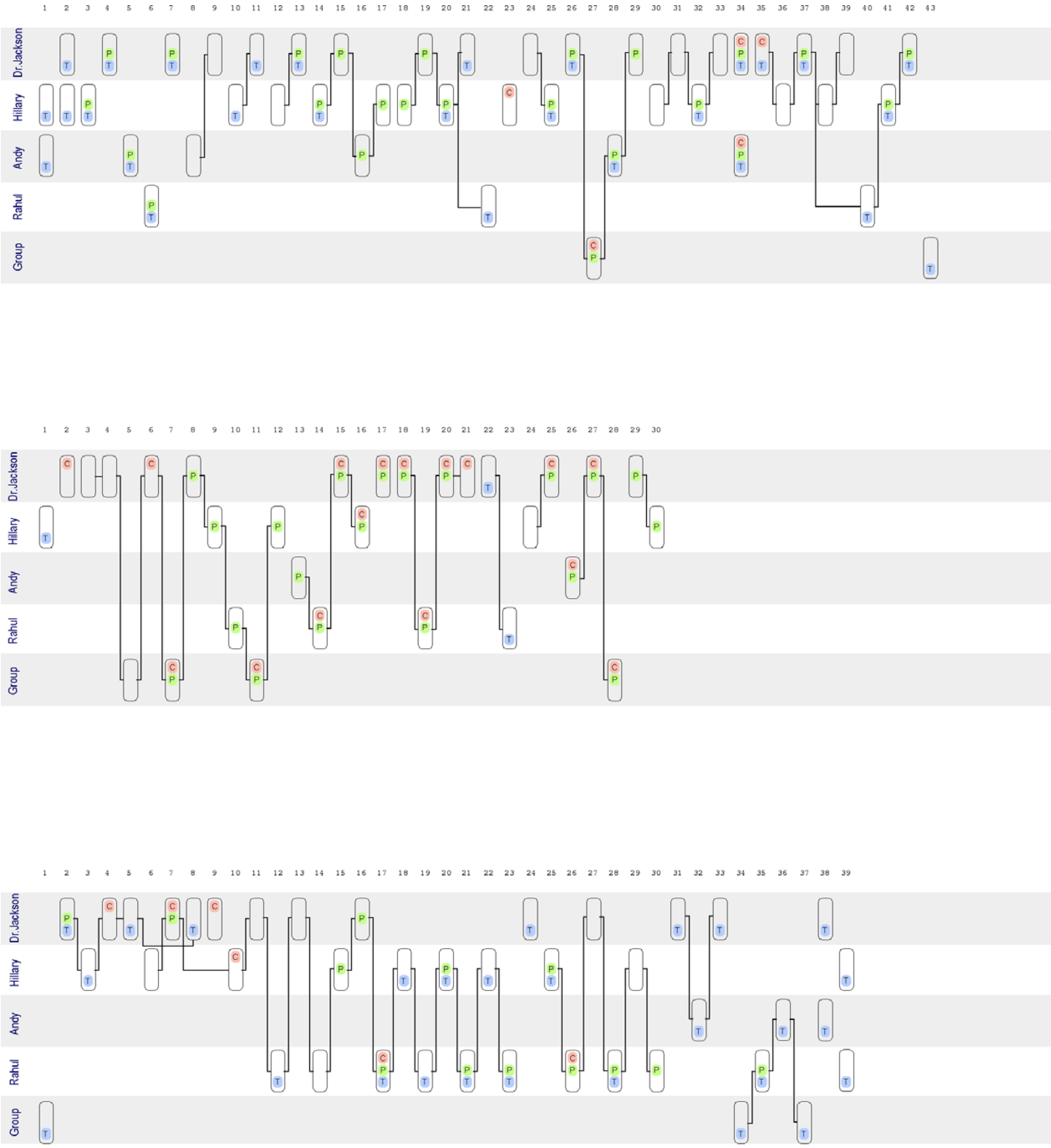

Fig. 5. Representation of the coded conversations for weeks 3, 8, and 15 of the course for Adams Family. Line segments represent topical threads.

comments drop in number considerably. These isolated segments are replaced with longer threads (for instance, one thread in the later-week spans 16 segments). This indicates that the group was beginning to have more sustained conversations around issues of design.

Curiously absent from the conversations of the Jackrabbit group are segments related to content. A close study of the coded notes indicates that this lack of discussion of content may have been driven by a decision made early on in the project by Dr. Jackson. Dr. Jackson decided that the course they were designing was best addressed as a series of topical cases. However, since she had not taught this class previously, she did not have any cases to provide her design team. Neither was she comfortable having the other members of the design team develop the cases. What this meant was that the group kept itself busy by initially working on getting a website up (learning technology) and discussing how they might teach these cases once they had some (pedagogy). The cases became hard to come by, and this made a significant difference to how this group worked. Consider some quotes from week six (see Koehler, 2003 for a complete transcript).

Dr. Jackson	"I don't know yet...I don't have a case...the cases available that I've looked at are not the ones that I see as could work in this situation...
Dr. Jackson	I have to write a case...then, well...
Dr. Jackson	I need you guys to develop the templates...how each piece could look like...

In other words, Dr. Jackson said she was unable to find suitable cases for the course, so she had to write one. In the meantime, she suggested, the group should continue to work on the web-templates (Technology). So, six weeks into the course, there was still only one member responsible for Content issues (Dr. Jackson) and the group as a whole only had technological and pedagogical issues to talk about. This division of labor stayed in place for the remainder of course, it seems, as Dr. Jackson had a hard time writing a case. Integrating content with the pedagogical and technological framework came later and later in the course. In week eight of the course, the students got to look at the first draft of a case Dr. Jackson had written, but the division of labor (Dr. Jackson dealing with content and pedagogy, the students pedagogy and technology) seemed to stay in place.

A further look at the graphical representation of the conversations (Fig. 5) shows a similar pattern for individual members of the group. The conversations from the early, middle, and late week of the course look quite similar. Content issues, when they are present in the conversation, primarily reside with Dr. Jackson or in the group (which we suspect means Dr. Jackson due to the previously described artifact problems of taking notes ascribed to the 'Group'); and, all members of the group (including Dr. Jackson) are likely to bring in technology issues (recall that Dr. Jackson had quite a bit of technology experience before joining the group). Also interesting are the number of short-lived threads about technology in the later week of the course. Dr. Jackson had just returned from a visit to the Virtual University (VU) regarding how the VU would implement, manage, and maintain her course. She had just been given a virtual tour of all the pieces that make a VU course (assessment modules, grading modules, communication tools such as threaded discussions, etc.). As such, the group was interested in exploring these and other tools (Dr. Jackson in particular).

Another noticeable difference between the Jackrabbits and Adams Family is the structure of the conversational threads (the connecting lines in Fig. 5). For the Jackrabbits, it is Hillary who seems to start and sustain many of the conversations in the early weeks, and to some extent in the later weeks of the course. That is, it is not always the faculty member who is the defacto "group leader" in the project groups. For whatever reason, Hillary was very interested (and vocal) about keeping the group productively employed, and making sure they could meet deadlines assigned by the instructor. The notes are replete with instances of this concern, for example consider this exchange from week 3 (Koehler, 2003):

Dr. Jackson	"You may feel disappointed...we are not going to have a full course at the end of this course, but we will have slots that can be filled later...when I have more to put into it..."
Hillary	"I'm only thinking of only the next two weeks...not the end of the semester...talking about the schedule..."
Dr. Jackson	"I can only give major headings on the syllabus during the next two weeks...once the headings are there, we can figure out what the page can look like..."
Hillary	"When can you give those?"
Dr. Jackson	"By the weekend...Sunday..."

Without the names attributed to the contributions, one might easily suspect that Hillary was the tenured faculty member, and Dr. Jackson was a student.

6.3. Comparing the two groups

There are certain similarities between the two groups. Both groups showed a change in their conversational patterns over time, reflected in the increasing length of conversational threads in their discussions. However, this surface similarity masks some interesting differences. The Adams' Family group seemed to show profound changes both at the group level and the individual level towards a more connected model of teaching that successfully integrates elements of technology, content, and pedagogy. The Jackrabbits, on the other hand, showed few of these changes towards a more integrated model. There are many possible reasons for these divergent results from a very similar problem solving design-based experience.

The simple one may be that design-based approach enables this growth to occur, but does not guarantee it. That is, we knew early on that the design approach is premised on the fact that faculty know the content and pedagogy, and that the students know more of the technology. The design approach, in theory, was to form the conditions whereby these two halves of the teaching puzzle could come together. Why did it not work for the Jackrabbits group? We suspect the problem stems from the early and persistent problem the Jackrabbits group experienced in getting content to work with. They were forced to think about content in the abstract for too long, when a design approach is premised on the promise of getting real experience early and often. In contrast, Dr. Adams had some early ideas about content, and even more importantly (we think), involved students early on in helping find materials and sources for additional content.

Another possibility might simply be interpersonal in nature. For whatever reason, the Jackrabbits may not have worked well together. Perhaps Dr. Jackson was unwilling or unable to "give up" control of the content. Perhaps the students in the group were unwilling or unable to grasp the content. Perhaps there was too much technology skill in the group resulting in conversations about their overly shared interests.

In either case, as designers of the approach, we think some potential changes in the course structure are worthy of pursuing. For example, future participants might benefit from our attempts to find more implicit and explicit methods for involving students in the content and faculty members in the technology so that the intellectual ferment we were looking for is more likely to happen.

7. Discussion

We collected rich field notes over the 15 weeks of the learning-by-design seminar for two different groups. This data was segmented and categorized based on our model of TPCK. This data was then analyzed both quantitatively and qualitatively to demonstrate the manner in which TPCK develops through engagement with authentic design tasks. Through quantitative analyses, we show that both design teams moved from considering technology, pedagogy and content as being independent constructs towards a more transactional and co-dependent construction that indicated a sensitivity to the nuances of technology integration (though one group did better than the other). At a qualitative level we developed a diagrammatic model to represent design talk. These diagrams that map the conversation help us see how the groups developed (or did not develop) in their thinking about teaching subject matter with technology. Our analysis shows both similarities and differences between the two groups at multiple levels. The groups evolved with time, both in terms of the roles played by the participants as well as the nature of meaning making within the groups. This suggests that developing TPCK is a multigenerational process, involving the development of deeper understandings of the complex web of relationships between content, pedagogy and technology and the contexts within which they function.

There have been some discussions in the literature about extending Schulman's idea of Pedagogical Content Knowledge (PCK) to the domain of technology (Hughes, 2005; Keating & Evans, 2001; Lundeberg et al., 2003; Margerum-Leys & Marx, 2002). We argue that bringing technology into the mix requires thinking of PCK as being one component of a broader framework that we call Technological Pedagogical Content Knowledge (TPCK). In our approach we have conceived of a model that offers three unitary components of knowledge (Content, Pedagogy and Technology), three dyadic components (Pedagogical Content Knowledge, Technological Content Knowledge, Technological Pedagogical Knowledge) and one overarching triad (Technological Pedagogical Content Knowledge). Effective technology integration for pedagogy around specific subject matter requires developing a sensitivity to the dynamic, transactional relationship between all three components taken together.

The idea of TPCK has significant implications for teacher education and teachers' professional development. In order to go beyond the simple "skills instruction" view offered by the traditional workshop approach, we have argued that it is necessary to teach technology in contexts that honor the rich connections between technology, the subject-matter (content) and the means of teaching it (the pedagogy). We have offered one possibility, that the *learning technology by design* approach explicitly foregrounds these connections. By participating in design, teachers are confronted with building a technological artifact while being sensitive to the particular requirements of the subject matter to be taught, the instructional goals to be achieved, and what is possible with the technology. The idea of *learning technology by design* is not a new one. However, we believe that the TPCK framework provides yet another argument for the pedagogical value of such activities, especially when considering the integration of educational technology in pedagogy.

There are certain fundamental challenges in representing teacher knowledge around technology (Fenstermacher, 1994), particularly as it develops in ''learning-by-design'' seminars. The first challenge is that any representation of teacher knowledge needs to reflect its collaborative, co-constructed nature. Furthermore, TPCK develops by doing and through the dialogues and interactions between the participants in design teams as they grapple with issues surrounding content, pedagogy and technology. Consequently, knowledge in such settings is not static or fixed. Thus any representation of teacher knowledge must capture this dynamic and evolving process. In this paper we offer multiple representational schemes that permit a close reading and analysis of the development and evolution of participant roles and meaning making in a design-based class.

There are of course some inherent limitations of the kind of analysis we have conducted. Qualitative content analysis can be subjective and interpretive (Berelson, 1952; Potter & Levine-Donnerstein, 1999; Rourke, Anderson, Garrison, & Archer, 2001). Though we have attempted to minimize subjectivity and enhance reliability we are sensitive to the fact that any claims being drawn from our research could be weakened if our coding scheme was flawed or biased in any way. That said, the fact that this study is consistent with other studies conducted with different methodologies (for instance, Koehler et al. (2004) which applied a case study approach; and Koehler and Mishra (2005b) that took a survey approach) does allay some of these concerns.

8. Conclusion

By introducing a model of technology that considers how the components of content, pedagogy, and technology co-constrain and intertwine, we have offered both a theoretical model (TPCK) as well as a potential analytical one for studying changes in teachers' knowledge about successful teaching with technology. In the data we presented here, we found that given opportunities to thoughtfully engage around the design of an online course, faculty and students alike showed tremendous growth in their sensitivity to the complex interactions between content, pedagogy, and technology – an important step for any faculty member about to enter the world of online teaching.

Our approach combining as it does pedagogical design, theoretical development, and educational research works as a complete package. Most research on educational technology has been criticized as being a-theoretical in nature, driven more by the imperatives of the technology than sound theory. We believe that the approach we have developed in this paper (and in other publications) can be the basis for a more integrated perspective on research and pedagogy. We believe such approaches can help bridge the gap between educational research and practice (Brown, 1992). Though we are hardly unique in this regard (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003; Design-Based Research Collective, 2003) we do believe that our approach can serve as a model for how to integrate research, pedagogy and theory development. In particular we offer an analytic framework for studying the nature and development of TPCK as the teams were involved in design work. Oftentimes, analysis of group discussions focuses on the nature of control and evolution of group dynamics. However, by using a lens suggested by our model, focus was directed instead to what is truly important – a coherent and nuanced understanding of technological-pedagogical-content knowledge.

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References

Berelson, B. (1952). *Content analysis in communication research*. Illinois: Free Press.

Blumenfeld, P. C., Soloway, E., Marx, R., Krajcik, J., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3&4), 369–398.

Brand, G. (1997). What research says: training teachers for using technology. *Journal of Staff Development, 19*(1), 10–13, Retrieved June 28, 2004, fromhttp://www.nsdc.org/library/jsd/brand191.html.

Bromley, H. (1998). Introduction: data-driven democracy? Social assessment of educational computing. In H. Bromley & M. Apple (Eds.), *Education, technology, ower* (pp. 1–28). Albany, NY: SUNY Press.

Brown, A. L. (1992). Design experiments: theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences, 2*(2), 141–178.

Bruce, B., & Levin, J. (1997). Educational technology: media for inquiry, communication, construction, and expression. *Journal of Educational Computing Research, 17*(1), 79–102.

Bruce, B. C. (1993). Innovation and social change. In B. C. Bruce, J. K. Peyton, & T. Batson (Eds.), *Network-based classrooms* (pp. 9–32). Cambridge, UK: Cambridge University Press.

Carver, S. M., Lehrer, R., Connell, T., & Erickson, J. (1992). Learning by hypermedia design: issues of assessment and implementation. *Educational Psychologist, 27*(3), 385–404.

Cobb, P., Confrey, J., diSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in education research. *Educational Researcher, 32*(1), 9–13.

Design-Based Research Collective (2003). Design-based research: an emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5–8.

Dewey, J., & Bentley, A. F. (1949). *Knowing and the known*. Boston, MA: Beacon.

Fenstermacher, G. D. (1994). The knower and the known: the nature of knowledge in research on teaching. In L. Darling-Hammond (Ed.). *Review of research in education* (vol. 20, pp. 3–56). Washington, DC: American Educational Research Association.

Flanders, N. (1970). *Analyzing teacher behavior*. Reading, MA: Addison-Wesley.

Fulton, K., Glenn, A., & Valdez, G. (2003). Three preservice programs preparing tomorrow's teachers to use technology: a study in partnerships. Retrieved on June 29, 2004, from http://www.ncrel.org/tech/preservice/.

Fulton, K., Glenn, A., Valdez, G., & Blomeyer, R. (2002). Preparing technology-competent teachers for urban and rural classrooms: a teacher education challenge. Retrieved on June 29, 2004, from http://www.ncrel.org/tech/challenge.

Hacker, D. J., & Niederhauser, D. S. (2000). Promoting deep and durable learning in the online classroom. In R. E. Weiss, D. S. Knowlton, & B. W. Speck (Eds.), *Principles of effective teaching in the online classroom* (pp. 53–64). San Francisco: Jossey-Bass [ED447767].

Handler, M. G., & Strudler, N. (1997). The ISTE foundation standards: issues of implementation. *Journal of Computing in Teacher Education, 13*(2), 16–23.

Harasim, L. M. (1987). Teaching and learning on-line: Issues in computer-mediated graduate courses. *Canadian Journal of Educational Communication, 16*(2), 117–135.

Harel, I., & Papert, S. (1990). Software design as a learning environment. *Interactive Learning Environments, 1*(1), 1–32.

Hickman, L. A. (1990). *John Dewey's pragmatic technology*. Bloomington, IN: Indiana University Press.

Hughes, J. E. (2005). The role of teacher knowledge and learning experiences in forming technology-integrated pedagogy. *Journal of Technology and Teacher Education, 13*(2), 377–402.

Iseke-Barnes, J. M. (1996). Issues of educational uses of the Internet: power and criticism in communications and searching. *Journal of Educational Computing Research, 15*(1), 1–23.

Kafai, Y. (1996). Learning design by making games: children's development of design strategies in the creation of a complex computational artifact. In Y. Kafai & M. Resnick (Eds.), *Constructionism in practice: Designing, thinking and learning in a digital world* (pp. 71–96). Mahwah, NJ: Lawrence Erlbaum Associates.

Kafai, Y. B. (1995). *Minds in play: computer game design as a context for children's learning*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Kafai, Y. B., & Resnick, M. (1996). *Constructionism in practice: designing, thinking, and learning in a digital world*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Keating, T., & Evans, E. (2001, April). Three computers in the back of the classroom: Pre-service teachers' conceptions of technology integration. Paper presented at the annual meeting of the American Educational Research Association, Seattle, WA.

Koehler, M. J., & Mishra, P. (2005a). Teachers learning technology by design. *Journal of Computing in Teacher Education, 21*(3), 94–102.

Koehler, M. J., & Mishra, P. (2005b). What happens when teachers design educational technology? The development of Technological Pedagogical Content Knowledge. *Journal of Educational Computing Research, 32*(2), 131–152.

Koehler, M. J., Mishra, P., Hershey, K., & Peruski, L. (2004). With a little help from your students: a new model for faculty development and online course design. *Journal of Technology and Teacher Education, 12*(1), 25–55.

Koehler, M. J. (2003). Transcripts from a design experiment. Available from http://mkoehler.educ.msu.edu/MattWeb/Data/DesignExperimentTranscripts.html.

Lehrer, R. (1991). Authors of knowledge: Patterns of hypermedia design. In S. Lajoie & S. Derry (Eds.), *Computers as cognitive tools*. Hillsdale NJ: Lawrence Erlbaum Associates.

Levin, J. A., Kim, H., & Riel, M. M. (1990). Analyzing instructional interactions on electronic message networks. In L. M. Harasim (Ed.), *Online education: perspectives on a new environment* (pp. 185–214). New York, NY: Praeger.

Loucks-Horsley, S., Hewson, P., Love, N., & Stiles, K. (1997). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin Press.

Lundeberg, M. A., Bergland, M., Klyczek, K., & Hoffman, D. (2003). Using action research to develop preservice teachers' beliefs, knowledge and confidence about technology. *Journal of Interactive Online Learning, 1*(4), Retrieved June 29, 2004, fromhttp://ncolr.uidaho.com/jiol/archives/2003/spring/toc.asp.

Margerum-Leys, J., & Marx, R. (2002). Teacher knowledge of educational technology: a study of student teacher/mentor teacher pairs. *Journal of Educational Computing Research, 26*(4), 427–462.

Mason, R., & Romiskowski, A. (1996). Computer-mediated communication. In D. Jonassen (Ed.), *Handbook of research for educational communications and technology*. New York: Macmillan.

Milken Exchange on Education Technology (1999). Will new teachers be prepared to teach in a digital age? [Online]. Retrieved June 28, 2004, from http://www.mff.org/publications/publications.taf?page=154.

Mishra, P., & Koehler, M. J. (in press). Technological pedagogical content knowledge: A new framework for teacher knowledge. Teachers College Record.

Mishra, P., & Koehler, M. J. (2003). Not "what" but "how:" Becoming design-wise about educational technology. In Y. Zhao (Ed.), *What teachers should know about technology: Perspectives and practices* (pp. 99–122). Greenwich, CT: Information Age Publishing.

Mishra, P., Spiro, R. J., & Feltovich, P. J. (1996). Technology, representation, and cognition: The prefiguring of knowledge in cognitive flexibility hypertexts. In H. van Oostendorp & S. de Mul (Eds.). *Advances in discourse processes* (Vol. LVII, pp. 289–305). Norwood, NJ: Ablex Publishing.

Mowrer, D. E. (1996). A content analysis of student/instructor communication via computer conferencing. *Higher Education, 32*, 217–241.

National Council for Accreditation of Teacher Education (1997). Technology and the new professional teacher: Preparing for the 21st century classroom. Washington, DC: National Council for Accreditation of Teacher Education. Retrieved June 28, 2004, from http://www.ncate.org/projects/tech/TECH.HTM.

Niederhauser, D. S., & Stoddart, T. (2001). Teachers' instructional perspectives and use of educational software. *Teaching and Teacher Education, 17*(1), 15–31.

Niederhauser, D. S., Salem, D. J., & Fields, M. (1999). Exploring teaching, learning, and instructional reform in an introductory technology course. *Journal of Technology and Teacher Education, 7*(2), 153–172.

Potter, W., & Levine-Donnerstein, D. (1999). Rethinking validity and reliability in content analysis. *Journal of Applied Communication Research, 27*, 258–284.

Riffe, D., Lacy, S., & Fico, F. (1998). *Analyzing media messages: quantitative content analysis*. New Jersey: Lawrence Erlbaum Associates, Inc.

Rosenblatt, L. M. (1978). *The reader, the text, the poem: the transactional theory of literary work*. Carbondale, IL: Southern Illinois University Press.

Rourke, L., Anderson, T., Garrison, D. R., & Archer, W. (2001). Methodological issues in the content analysis of computer conference transcripts. *International Journal of Artificial Intelligence in Education, 11*(2), 8–22.

Schulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 414.

Schulman, L. S. (1987). Knowledge and teaching: foundations for a new reform. *Harvard Educational Review, 57*(1), 1–22.

Schwandt, T. A. (1997). *Qualitative inquiry: a dictionary of terms*. Thousand Oaks, CA: Sage.

Sinclair, J., & Coulthard, M. (1975). *Towards an analysis of discourse*. London: Oxford University Press.

Strudler, N., & Wetzel, K. (1999). Lessons from exemplary colleges of education: factors affecting technology integration in preservice programs. *Educational Technology Research and Development, 47*(4), 63–81.

U.S. Congress Office of Technology Assessment (1995). *Teachers and technology: Making the connection*. Washington, DC: Office of Technology Assessment.

U.S. Department of Education, National Center for Education Statistics, (2000). Teachers' tools for the 21st century: A report on teachers' use of technology. Washington, DC: Authors. Retrieved September 6, 2004, from http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=2000102.

U.S. Department of Education, National Center for Education Statistics, (1999). Teacher quality: A report on the preparation and qualifications of public school teachers. Retrieved June 28, 2004, from http://nces.ed.gov/pubsearch/pubsinfo.asp?pubid=1999080.

Zhao, Y., Conway, P., (2001). What's in and what's out?: An analysis of state technology plans. Teachers College Record. Retrieved June 28, 2004, from http://www.tcrecord.org/Content.asp?ContentID=10717.

Zhao, Y. (Ed.). (2003). *What should teachers know about technology: perspectives and practices*. Greenwich, CT: Information Age Publishing.