Opportunities to Learn Through Design: Mapping Design Experiences to Teacher Learning

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Abstract: This paper examines the ways in which specific design experiences lead to certain types of learning. We engaged thirteen community college instructors in iterative design through Plan-Do-Study-Act (PDSA) cycles to design and develop new developmental mathematics lessons. In this study, as in most design-partnerships, teachers touch only some aspects of the design process. In the work reported here, we make explicit the varying ways in which instructors took part in PDSA cycles and examine the types of knowledge generated by their participation. We use Edelson (2002) as a lens to categorize learning into three types: domain, design framework, and design methodology. Results indicate that instructors do not need to be involved in every aspect of design to learn. Our findings highlight the role time plays on engagement and learning in design. Implications for design efforts, to the extent they are focused on learning, are discussed.

Introduction

Increasingly, education practitioners, policy makers, and researchers recognize that teaching quality is key to student achievement (Darling-Hammond & Richardson, 2009). The link between high-quality professional development and student outcomes is sound (Borko, 2004; Desimone, 2009); however, only recently have researchers become concerned with deciphering the underlying, and often messy, links between professional development conditions, what and how teachers learn, and transformation of classroom practices (Borko, 2004; Clarke & Hollingsworth, 2002). This study seeks to contribute to this growing body of literature, probing how teacher engagement in design can foster meaningful learning and promote changes in classroom practice.

A number of studies point to design as a site for teacher learning (Gomez et al, 2015; Koehler & Mishra, 2005; Voogt, 2015). Design is the systematic development of an educational innovation (e.g: curricular material, technology) to support some aspect of student learning (Edelson, 2002; Joseph, 2004). Edelson (2002) conjectures that if one participates in design processes, s/he will have many opportunities to learn. Most commonly, however, teachers, less often the engines driving the design effort (Penuel, Fishman, Yamaguchi & Gallagher, 2007), participate in only some elements of design. Thus, to better understand what teachers can learn as they engage in design, we must understand how specific design experiences lead to certain types of professional learning. Although the current literature is sparse, we posit that it would be fruitful to probe opportunities to learn in specific aspects of the design experience.

We report results from a two-year study, where we take up this question. We engaged 13 community college instructors in Plan-Do-Study-Act (PDSA) cycles (Langley et al., 2009), our design methodology guiding the iterative design of developmental mathematics lessons. We make explicit the varying ways in which instructors, who are critical to the design effort but do not drive the design process, took part in PDSA cycles, and examine the types of knowledge generated by their participation.

Community college developmental mathematics classrooms are important sites for learning by design. Efforts to increase the quality of teaching are gravely needed. Yet this problem receives relatively little attention (Boylan, 2002; Stigler, Givvin & Thompson, 2010). Each year, over thirteen million students enroll in community colleges across the U.S. For 59% of these students, the dream of graduation is quickly shattered when they are placed into developmental, or remedial, mathematics courses (Bailey, Jeong, & Cho, 2010). With a 30% success rate (Levin & Calcagno, 2007), developmental mathematics have been called the “graveyard of dreams and aspirations” (Merseth, 2011). Students are often doomed to retake courses, resulting in prolonged enrollment, increased debt, and in many cases, eventual dropout (Stigler, Givvin & Thompson, 2010). A core assumption of this paper is that professional development could figure largely in the reform of developmental mathematics. As such, we seek to examine ways in which developmental mathematics instructors learn through engagement in design as a means to improve instructional practices, and in turn, student outcomes.

Design as professional development

Studies that explore the potential of design for professional learning suggest that the elements of design key to learning include: situating learning in practice (Joseph, 2004); active inquiry into the problem (Koehler & Mishra, 2005; Kolodner et al., 2003), sustained and organized engagement (Collins, 1992; Koehler & Mishra, 2005), and collaboration (Voogt, 2015), as they align with key characteristics of effective professional development (Borko, 2004; Desimone, 2009; Little, 1990). Active and situated learning opportunities allow teachers to integrate new knowledge with existing knowledge (Davis & Krajcik, 2005), resulting in meaningful and authentic learning (Greeno, 1998). Using cyclical attempts to improve the intervention, designers learn most in their moments of failure. When one aspect of the design does not work, designers must reason through the ways different design elements work together, considering how change to one area of design may impact another (Collins, 1992). This decision-making process, requiring exploration of nuanced relationships between the tool, students, and local context (Koehler & Mishra, 2005; Krajcik et al, 1998), provides designers with important opportunities to learn (Edelson, 2002). Disciplined inquiry, coupled with the collaborative nature of design, provides a venue for instructors to encounter distributed knowledge as they take part in purposeful discourse with collaborators from diverse backgrounds. Such collaboration can be transformative as it allows designers to gain increased awareness of their own practices and beliefs (Koehler & Mishra, 2005).

Design is sustained over time and organized, another important characteristic that supports learning. The use of cyclical testing to develop optimal design solutions (Collins, 1992; Koehler & Mishra, 2005; Kolodner et al., 2003) naturally extends participation in design over time. There is a growing consensus that professional development that is sustained over longer periods of time presents increased opportunities for teachers to assimilate new knowledge into practice (Desimone, 2009). Studies have shown that when not given enough time in professional learning, teachers often do not retain what they learn and evidence little change in classroom practice (Coburn, 2004). Other scholars suggest that extended duration is not enough, and that time must be organized into structured activities, with purpose, to produce effective change (Garet, Porter, Desimone, Birman & Yoon, 2001). Adherence to a specific a design methodology provides this organization, guiding those participating in design through design activities (Collins, 1992).

In this study, we ask, what is the relationship between kinds of design contact and specific opportunities to learn? The guiding hypothesis of this paper is that amount of time instructors spend in design may have consequences for the quality of their engagement in design activities and professional learning generated. We follow Edelson (2002) to explore three types of learning: 1) domain learning, which refers to increased knowledge about the design setting, such as increased understanding of the language and literacy needs of developmental mathematics students; 2) design framework learning, or an instructor's increased understanding of the design ideas involved in the design solution (in this case, mathematics, language and literacy tools, problem situation, and pedagogy in the new lesson); and 3) design methodology learning, which indicates an instructor's increased understanding of the design procedures, or in this study, PDSA cycles.

Methods

This study focuses on the collaborative design of 12 new developmental mathematics lessons. Our design goals were to contextualize lessons and reduce language barriers. Contextualization, or the integration of academic and occupational curricula, engages students in real-life, authentic problems resulting in more meaningful learning, making it easier to internalize, understand, transfer, and retain (Herod, 2002).

Participants. We examined data from 13 instructors from 6 community colleges across the U.S., who participated in lesson testing. Instructors volunteered to participate, and received a small honorarium for their work. Instructors engaged in design in varying ways (see Table 1*)*; this allowed us to examine the ways in which specific design activities generate learning. We will detail this involvement in the next section.

PDSA Cycles. We used Plan Do Study and Act (PDSA) cycles to guide the developmental arc of the design work. An Improvement Science tool, PDSAs are characterized by quick iterative learning, fast failure, and rapid refinement (Langley et al., 2009). Instructors touch the PDSA cycles in the following ways. Our cycles began with a few instructors teaching the same lesson. "PLAN" occurs as instructors prepare to enact the lesson. "DO" occurs as instructors conduct a test by enacting the lessons. Within two days of enacting a lesson, instructors participated in either a follow-up semi-structured, open-ended interview (Seidman, 2006) or a survey aimed to gain insight into instructor experience teaching the lesson and recommendations for refinements. "STUDY" includes instructor's participation in these interviews and surveys. We then collected and analyzed data from lesson enactments, summarized results, and made quick revisions to the lesson before a new cycle of instructors tested the same lesson. "ACT" occurs as faculty, along with the design team, work out the plan for the next testing cycle. These cycles continued until all participants taught the lesson. Halfway through the PDSA cycles, we made intermediate refinements to the lesson based on more extensive data analysis. At the end of testing, six of the thirteen participants attended a two-day design workshop to make long-term changes to the lessons. Participation in this meeting falls under "ACT"[1]. The use of PDSA cycles allowed the design team to manage design revisions efficiently, as team members decided when and how design changes should be addressed. PDSAs recognize that straightforward design changes could be implemented immediately while more complex changes were put aside for later revisions. Data resulting from instructor engagement in PDSAs include: 51 instructor interviews, 52 instructor surveys, artifact design changes (documented changes within and across lessons), and ethnographic field notes of the 2-day instructor design meeting.

Table 1: Instructor Engagement in PDSAs

Frank: designed 4 lessons, enacted 9 lessons, 9 interviews, 9 surveys, design meeting	**Catherine**: enacted 7 lessons, 6 interviews, 5 surveys, ½ design meeting	**Kelly**: enacted 2 lessons, 2 interviews, 2 surveys
Nate: designed 8 lessons, enacted 8 lessons, 4 interviews, 4 surveys, design meeting	**Maria**: enacted 3 lessons, 3 interviews, 3 surveys, design meeting	**Ted**: enacted 2 lessons, 2 interviews, 2 surveys
Kyle: enacted 9 lessons, 9 interviews, 9 surveys, design meeting	**Natalie**: enacted 3 lessons, 3 interviews, 3 surveys	**Kristen**: enacted 2 lessons, 1 interviews, 2 surveys
Henry: enacted 9 lessons, 9 interviews, 9 surveys, design meeting	**Nancy**: enacted 3 lessons, 2 interviews, 1 surveys	**Quincy**: enacted 3 lessons, 2 surveys
		Dana: enacted 1 lesson, 1 survey, 1 interview

Data Analysis. We analyzed design workshop ethnographic field notes, transcribed interviews, interview notes, survey responses, and artifact design changes. We coded instances of professional growth using Clarke and Hollingsworth's (2002) Interconnected Model of Professional Growth (IMPG). In accordance with the model, we coded for changes in: 1) knowledge, belief, or attitudes; 2) classroom practice; 3) salient outcomes; and 4) use of new materials. This allowed us to identify instances of change and determine where learning occurred. In the second cycle of coding, Edelson's (2002) framework guided our coding for three types of learning: domain learning, design framework, and design methodology. This allowed us to understand the types of instructor learning generated by design participation.

Table 2: Duration and Engagement

High Design Time Group (HDT)	
HDT Participants	***High Engagement Scores***
Nate 106 Frank 79.5 Kyle 39.5 Henry 39.5 Maria 26.5 Catherine 23	Catherine 5 Frank 4.69 Henry 4.67 ***Low Engagement Scores*** Nate 4.42 Maria 4.21 Kyle 3.56
Low Design Time Group (LDT)	
LDT Participants	***High Engagement Scores***
Natalie 10.5 Nancy 8.5 Ted 7 Kelly 7 Quincy 4 Kristen 4 Dana 3.5	Natalie 4 Nancy 5 Ted 5 Kelly 5 ***Low Engagement Scores*** Quincy 2.83 Kristen 2.25 Dana 3

Table 3: Duration and Learning

High Design Time Group (HDT)	
HDT Participants	***More Learning Scores***
Nate 106 Frank 79.5 Kyle 39.5 Henry 39.5 Maria 26.5 Catherine 23	Nate 28 Frank 20 ***Less Learning Score*** Henry / Maria 6 Catherine / Kyle 4
Low Design Time Group (LDT)	
LDT Participants	***More Learning Scores***
Natalie 10.5 Nancy 8.5 Ted 7 Kelly 7 Quincy 4 Kristen 4 Dana 3.5	Ted 3 Natalie / Quincy 1 Kristen 1 ***Less Learning Scores*** Nancy / Kelly/ Dana 0

Given the variation in instructor involvement in PDSA cycles, we developed a scoring system to stratify participants into groups based on their number of hours engaged in design activities, quality of engagement, and learning generated by participation in design. First, we calculated participants' total hours spent in design work (including lesson enactment) and performed a median split to separate the top and bottom 50% in regards to total time spent on design (duration ranges from 3.5-106 hours). Within each 'design time' category, we performed a sub-split to compare instructors on the basis of quality engagement (high or low) (see Table 2). The authors gave each participant an engagement score using a Likert scale (low engagement=1 and high engagement=5) based on his or her willingness to give feedback on classroom experiences and provide design revisions in each design opportunity (engagement scores range from 1-5). The authors scored engagement individually (interrater reliability is 84%), and inconsistent scores were averaged. We then created a second system using the initial 'design time' median split to perform a sub-split on the basis of learning (high or low) (see Table 3). Learning scores take into account the number of instances of teacher change and the kinds of learning generated (domain, design framework, and design methodology), and range from 0-28. The goal was to examine the following relationships: 1) the relationship between design time and level of engagement, and 2) the relationship between design time and learning. Given that research supports the learning potential for sustained, meaningful professional development (Garet, Porter, Desimone, Birman & Yoon, 2001), we predicted that we would find a positive relationship between design time and engagement and instructor learning.

Findings

We used qualitative methods to uncover the ways in which engaging in key elements of design might lead to learning. Our findings are limited by the small sample size that rendered inferential testing less optimal for examining the relationship between design time and engagement and learning. Our intention was not to establish correlation or cause, but rather to initially characterize the broad outlines of phenomena that might connect design experience to professional growth.

The results of this study suggest the relationship between design time, design engagement, and teacher learning are more complex than predicted. That is, an increase in design time was not always associated with an increase in engagement or learning. Our findings in the *High Design Time* (*HDT*) group do suggest, however, that a relationship exists between duration of engagement and types of learning when instructors engage in at least 20 hours of design work, consistent with Desimone (2009). Our findings support Edelson's (2002) perspective; ten out of thirteen instructors showed evidence of professional learning in at least one of three categories of learning: design domain, design framework, and design methodology. In what follows, we describe in more detail the relationship between duration and engagement and duration and instructor learning.

Duration and engagement

The results of our analysis found the relationship between amount of time spent on design and level of engagement to be unclear. Some instructors received engagement scores (ranging from 0-5) comparable to their design time (ranging from 3.5-106 hours). For example, all three instructors who participated in less than five hours of design work showed a low level of engagement (≤3). However, in most cases, the scores were unpredictable. For example, three *Low Design Time (LDT)* instructors earned the maximum engagement score of 5, outscoring most of their *HDT* counterparts. The results of the level of engagement surprised us for particular instructors even within design time groups. Catherine, who only spent 23 hours on design work, was the most engaged instructor in the *HDT* group with a score of 5. Nate, who participated in lesson design and spent the most time in design activities (106 hours), received only the fourth highest engagement score (4.42).

Duration and learning

Our findings indicate that increased duration of engagement in design activities is linked to increased and varied types of learning. Learning scores range from 0-28. The *HDT* instructors (duration ranging from 23-106 hours), and four of seven *LDT* instructors (duration ranging from 3.5-10.5 hours) showed evidence of domain learning. All six of the *HDT* instructors, but only one of the seven *LDT* instructors showed evidence of design framework learning. Only one *HDT* instructor of the thirteen total participants showed increased understanding of PDSA cycles, our design methodology. In all cases, the *High Design Time* (learning scores range from 4-28) instructors learned more than their *Low Design Time* counterparts (learning scores range from 0-3).

High Design Time (HDT) group

Our findings in the *HDT* group suggest that a relationship between time spent in design and learning may exist, but another variable may be at play. The *HDT* instructors were the only instructors in the study to participate in

“ACT” activities, which engaged instructors in making design decisions with researchers to refine the lessons. In the *HDT* group a relationship between time spent in design and learning clearly exists, as we predicted. Instructors in this group participated in 23-106 hours of design work, and instructor learning scores range from 4-28. Instructors Frank and Nate, who co-designed the initial lesson drafts with researchers, participated in > 75 hours of design work and evidenced the highest learning scores (≥20). The other four instructors in the *HDT* group engaged in only 20-40 hours of design work and evidenced lower learning scores (≤6). While it seems that increased duration leads to increased learning, there is some unexpected variation within the “low-learning” group. Kyle had the highest number of design hours (39.5 hours) within the “low-learning group” yet had the lowest learning score (4), while Maria participated in only 26.5 hours of design, but generated a learning score of 6. Interestingly, Maria, like Kyle, had low a score of engagement, suggesting that engagement may not relate to instructor learning. It is important to note that while learning scores vary based on the number of occurrences, all instructors in the *HDT* group showed instances of learning about the domain and design framework, while only one evidenced learning about the design methodology. In what follows, we provide examples of the specific types of learning generated in the *High Design Time* group.

Learning about the Design Domain. All six *HDT* instructors exhibited increased domain knowledge. For example, throughout nine lesson enactments, Henry learned about the interactions between the local setting and the Comprehension and Synthesis[2] (CaS) Chart (see Figure 1), a language and literacy tool critical to our design. He showed a change in his beliefs about the usefulness of the CaS chart for his students, which resulted in a shift in his instructional practices, and in turn, student outcomes. Following the first lesson, Henry said: “...I like it,think it’s useful…fits my feeling of how we should approach information mathematically. It will help students figure out what they’re doing before they put a number on it.” (Henry Interview, 1st enactment). However, his students did not necessarily agree: “There is some distrust over the system whether this [CaS chart] is going to be beneficial to students. Students are unsure about how to complete the CaS chart. They especially struggle with Column C” (Henry Interview, 1st enactment).

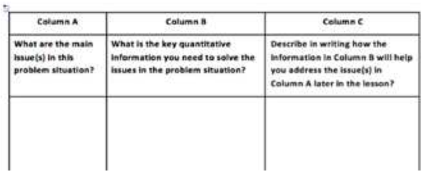

Figure 1. The CaS Chart.

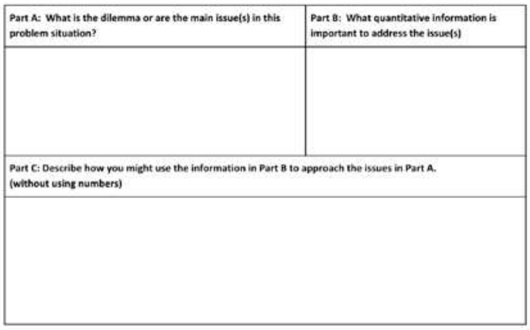

Figure 2. Kyle’s Adapted CaS Chart.

However, by the ninth lesson enactment, Henry gained insight into the usefulness of the CaS chart for his students, resulting in a shift in instructional practice: “I talk about the CaS as a tool for helping them understand reading…separate thinking into small parts, and start to organize a strategy for calculating...Thinking through a strategy before calculating is something I’ve added to the discussion about the CaS chart.” (Henry Interview, 9th enactment). Henry evidenced the impact of this change on student learning, reflecting on his enactment of the CaS Chart with a new class:

> Students gave decent reviews of the Cas Chart...reporting verbally that it was worth the time to talk things out and sort information. One student specifically said that this [CaS Chart] matched the way she likes to think…Both classes…recognized the value of Column C… They were thinking about how they might approach the problem before they dive into it. We had…positive vibes from the class as they were discussing what they've found in that third column.” (Henry Interview, 9th enactment)

It is important to note that while this data evidences what domain learning looks like, other examples of design domain learning do not evidence the impact of instructor learning on student outcomes, as this example does.

Learning about the Design Framework. All six *HDT* instructors learned about the design framework. In this example, Kyle learned about the core ideas behind creating language and literacy supports. After his first enactment of the CaS chart, Kyle reflects: “Having the two columns filled in with examples was helpful as acquiring the tool and material at the same time isn’t good. I don’t think the CaS chart was useful this time because of the scaffolding. It might become useful in the future when they do it on their own." (Kyle Interview, 1st enactment). Following the second enactment, Kyle re-evaluates his belief that scaffolding is useful: "You should get rid of the scaffolding. It's still not useful. You should introduce the CaS chart in a short lesson on it's own." (Kyle Interview, 2nd enactment). In the first two lesson enactments, Kyle builds understanding of how the design of CaS chart (i.e: scaffolding) impacts students. Following this cycle of testing, Kyle reflects with instructors and researchers about the purpose and formatting of the CaS chart, "Column C seems superfluous by the time Column A and B are completed. The directions instruct students to complete column A then B then C, but it is more cyclical. Students should know that it is an iterative process." (Kyle, Instructor Design Meeting) Kyle developed a new version of the CaS chart, adapting it to fit his students' needs (see Figure 2). He has continued to use this adapted version of the CaS chart in his classes, and is presenting his adapted version of the CaS chart at a practitioner's conference this year.

Learning about Design Methodology. Only Maria, a *HDT* instructor, showed evidence of increased understanding of PDSA cycles. While PDSAs guided and documented design activities, instructors did not use them directly. Maria became familiar with PDSAs through her participation in design activities, including interviews, surveys, and participation in the in-person meeting. As a result of this familiarity with PDSAs, Maria is presenting PDSA as a tool for curriculum development to colleagues, and has sought additional consultation with the research team to gain a better understanding of this design methodology. Although it is unlikely that Maria would have gained familiarity with PDSAs without engagement in this work, without Maria's subsequent presentation as a external prompt, increased duration would not likely result in design methodology learning.

Low Design Time (LDT) group

The relationship between duration and learning is unclear in the *LDT* group. Instructors in this group participated in 3.5-10.5 hours of design work, with learning scores ranging from 0-3. Two of the four instructors with the most design time (7-10 hours) were also in the "high learning" group, but Nancy, who spent the second highest amount of time in design (8.5 hours), and Kelly (7 hours) do not evidence learning at all. In contrast, Quincy, who only engaged in four hours of design, evidenced one instance of learning. In the *LDT* group, four of seven instructors evidenced learning; three increased design domain knowledge, but only one, Ted, evidenced learning about both design domain and design framework. In this example, Ted builds his understanding about how the underlying design ideas of the Double-Entry Journal (DEJ), a language and literacy tool, interact with the time allotment for his class as he engages in a post-enactment survey and interview. This is an important example because it provides evidence that engaging in "STUDY" activities may lead to learning.

Before the interview, Ted completed a survey providing feedback on the lesson, in which he wrote: "You may want to consider using the DEJ with a shorter lesson." (Ted Survey, 1st enactment). During the interview, Ted discusses two different ways to save time while still including the DEJ:

> It's just a lot of reading. It might be helpful for students to see a copy of the DEJ upon completion of the reading so that they would not have to go back and reread the introductory instructions…the task [DEJ] is out of context. I think it would have more meaning if they had it in the context of the lesson…Then question six...You could use the DEJ there. In the [left column of the DEJ] say 'Yes' or 'No' and 'Why', in the [right column of the DEJ] have students use statistics to back up [the left column]. You could take most questions and turn it into a DEJ. (Ted Interview, 1st enactment)

Through DEJ enactment and reflection in the interview, essential components of PDSAs, instructor Ted learned how to reach a design solution that would address students' needs, rather than simply eliminate the DEJ. The two ideas he presented in the interview, displaying the chart for students after the reading and embedding the chart in existing mathematics questions are evidence of Ted's learning about the DEJ's importance.

Ted spent the median number of hours (7) engaged in design work in the *LDT* group, but received the highest learning score (3). Why did Ted stand out amongst his colleagues, as other instructors with similar design time and engagement scores did not exhibit any learning at all? Nancy and Kelly, who spent 8.5 and 7 hours on design, respectively, received learning scores of zero, but like Ted, received the highest engagement score possible. This suggests that either engagement is unrelated to learning for these instructors, or that Nancy and Kelly learned in ways that we could not capture using the Edelson (2002) model.

Discussion

Very commonly, instructors involved in design-partnerships only engage in some elements of design. We have offered some granular, though very preliminary, evidence of how engagement in specific elements of design contributes to certain types of learning. This work helps us understand the role of time in design experiences. The relationship between learning and time spent in design activities seems clear for instructors who participated in more than 20 hours of design work, but this relationship is less apparent for the *LDT* group. Further, the relationship between duration and engagement remains unclear. It is possible that some instructors learned information that was not captured in our current analysis. The relationship between engagement and learning might also have impacted our findings. That is, instructors who were not as engaged during design meetings or phone interviews may not have vocalized their learning. Future research should examine more explicitly the relationship between engagement and learning.

In our analysis of instructor learning an unexpected category of learning emerged: pedagogical design capacity (PDC), an instructor's ability to recognize and employ resources to adapt existing, or develop new, instructional materials (Brown & Edelson, 2003). In this work, five of the thirteen instructors (and, in the *HDT* group, five out of six) adapted lessons to better support their students' needs (Barab & Luehmann, 2003). Adaptations included changes to the language and literacy tools embedded in the lessons (as evidenced in Kyle's example above), creating additional mathematics questions, developing and integrating examples in areas where students struggle, and developing new problem contexts. As it became clear that the time instructors spent in design work played a role in kinds of learning, we began to see that PDC is consequential, resulting from the confluence of increased understanding of the design domain and design framework. Of the five instructors who evidenced increased PDC, none evidenced learning about design methodology; thus, we do not believe that this is a critical category of learning in the development of PDC. Although PDC is indicative of certain types of learning, we argue that it is, in itself, an important type of learning generated from design, as adaption of curricular materials to align with local needs is critical for effective implementation (Barab & Luehmann, 2003). It is important to note that all instructors who evidenced PDC engaged in "ACT" design activities, while the others (with the exception of 1 (Maria)) did not. While this may be a significant factor in developing towards PDC, more work must be done to better understand this relationship. While this study evidences increased PDC in instructors, it does not shed light on the alignment of adaptations to designers' intentions; future work is necessary to understand how to support instructors in adapting materials to meet their needs while maintaining integrity of the design solution (Davis, Beyer, Forbes, & Stevens, 2011).

Our findings highlight the opportunities for learning provided by design. Importantly, these results suggest that participation in design work can take on different forms; teachers do not necessarily need to be involved in every aspect of the design process to learn from the experience. Instructors in this work differed in duration and forms in which they were involved with PDSA cycles. In general, our findings suggest that instructors who spent more time in design experienced more learning. Yet, four of the seven instructors who spent less than 10.5 hours in design showed evidence of learning, suggesting that even a short period of design activity can present a learning opportunity. However, more work, which systematically assigns instructors to specific PDSA activities, keeping duration the same, must be undertaken to better understand the relationship between PDSA activities and learning. For example, the 6 instructors who participated in "ACT" activities were also in the *High Design Time* group. All instructors participated in "PLAN", "DO", and "STUDY" activities, however, increased participation in these activities also increased overall duration spent in design activities. With the exception of Ted, who evidenced immediate learning as a result of participation in a "STUDY" activity, our data is insufficient to parse how engagement in specific PDSA activities generate learning.

This work has important implications for future design efforts, especially in models concerned with professional learning, that engage teachers in some, and not all, elements of design. We argue that it is critical, as we did with PDSA cycles, to keep track of instructor duration, the ways in which instructors touch design, and quality of engagement. The use of PDSA cycles allowed us to trace the evolution of both the lessons and participants. With each iteration, informed by the instructors, the PDSA cycles captured design problems and potential solutions. Thus, we were able to simultaneously gain insight into the lessons themselves, as well as the people who were enacting them. We believe that embedding these practices in design work provide a rich way of talking about the kinds of learning generated from design.

Endnotes

(1) All 13 instructors participated in "PLAN", "STUDY", and "DO" activities, but only the six instructors at the design meeting participated in "ACT" activities. We did not collect data on "PLAN" activities.

(2) The CaS chart is a tool the researchers developed to support student comprehension in mathematics word problems.

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