Cross-disciplinary Participatory & Contextual Design Research: Creating a Teacher Dashboard Application.

Troy D. Abel[1], Michael A. Evans[2]

[1] School of Visual Arts, Department of Visual Communication Design
Virginia Tech, Blacksburg, Virginia 24061 USA
[2] School of Education, Department of Learning Sciences and Technologies
Virginia Tech, Blacksburg, Virginia 24061 USA
{tabel,mae}@vt.edu

Abstract. Concepts of Human Computer Interaction have crossed disciplinary boundaries allowing the discovery of underlying stakeholder affordances to emerge during the design research phase of system design. For the current scenario, middle school mathematics teachers as data-driven decision makers are inundated with diagnostic and assessment data, resulting in data deluge. The situation is unlikely to subside as digital technologies and media are broadly adopted for instruction and learning. Teachers could benefit from tools to quickly sift through this data to inform classroom instruction. Data should be visualized in a way that teachers can make real-time formative and summative assessments of student progress. The purpose of this article is to introduce a mixed-method mode of discovery to uncover affordances innate to classroom teachers during the design of an iPad data visualization application. These technology-assisted "dashboard" platforms could serve as efficient and effective interventions to deal with the copious amounts of data streams now available to teachers.

Keywords: decision-making, teaching and learning, mathematics education, participatory design, cross-disciplinary research, data visualization.

1 Introduction

Given the increased emphasis on data-driven decision-making, middle school mathematics teachers are inundated with what has been referred to as the data deluge (NSF, 2008) [1]. In the context of this environment, our proposal is that classroom teachers could benefit from technology-assisted data visualization platforms to efficiently and effectively deal with copious data streams, in real-time, enabling them to make sound instructional decisions [2]. In fact, the U.S. Department of Education [2] has emphasized in a national educational technology plan, that:

With assessments in place that address the full range of expertise and competencies reflected in standards, student-learning data can be collected and used to continually improve learning outcomes and productivity [3].

In this paper we detail the process of conducting participatory design sessions with six (6) middle school mathematics teachers and one (1) instructional technology resource teacher (ITRT) in an effort to derive priorties for a *teacher dashboard*. The exercises and prototypes are aligned with the implemenation of mathematical learning games in the classroom that target areas such as fractions, coordinating units, and proportional reasoning. This paper highlights interdiscipliantry efforts among mathematics educators, learning scientists, and human-computer interaction experts. In the following, we detail the context in which activities occur, as well as milestones and prototypes that emerged through the process. Our goal is to develop a usable application whereby teachers can make evidence-based decisions to improve teaching and learing in the middle school mathematics classroom.

1.1 Background Information

The reported efforts are part of a larger project to introduce iPads (n=180), learning video games, and interactive assessments to six middle school mathematics classrooms in under-performing rural areas of southwest Virginia. The goal of the three-year project is to improve pre-algebra mathematics instruction and learning by investigating the interactions among achievement, engagement, and interactive media [4].

The CandyFactory App, developed for the iOS platform (primarily targeting iPads), is a learning game intended to support students' understanding of fractions and thus promote algebra-readiness. In working with fractions, most 6th grade students in the U.S. rely on part-whole conceptions alone, inhibiting development toward algebra in higher grades. In a mixed-methods design study, investigators documented the theoretical and evidence-based approach to designing, developing, and piloting a learning game for algebra readiness. Initial results indicated that the game achieved intended goals, scaffolding learners in their development of appropriate mental actions while engaging with game mechanics. The CandyFactory App differed from existing serious video game apps along three dimensions: 1) the app is designed following evidence-based theories of cognition and engagement; 2) the app supports a fractions learning trajectory; and 3) the app leverages game mechanics and device hardware for formative assessment purposes [5]. Given preliminary evidenence that CandyFactory App positively incluences student understanding of fractions, a next step is to assist teachers in leveraging this evidence for sound decision making in the classroom. The direction we focus on is data visualization solutions in an app format.

Research and development on a data visualization app for teachers, which leverages the video games and interactive assessments being developed in parallel, combines several disciplines and theories. Human-Computer Interaction (HCI) and Visual Communication Design serve as the foundational fields in reported efforts, complemented by Instructional Design and Technology, and Computer Science. Participatory Design and Activity Theory are conceptual frameworks advocated to uncover affordances and opportunities in the design of a real-time, data-driven, data visualization iPad application (codename: “teacher dashboard”) and the companion student mathematics application for middle school mathematics.

1.2 Initial Research Questions

Three resulting research questions guide this interdisciplinary effort:

1. What essential, real-time data do middle school mathematics teachers need to make sound, intentional decisions in the classroom within the scope of the larger project?
2. How can data from student performance on educational game-based learning be experienced to maximize decision-making processes?
3. How can such data representations be enhanced through multimodal interaction (sound, visuals, motion, haptics, etc.) for analytical purposes?

In the context of this article, research question 1 has been explored using various modes of inquiry to be reported below. We position this as an iterative model of design and development, research questions 2 & 3 to be addressed in Fall 2014.

1.3 Augmented Research Questions

Several questions emerged during discussions amongst investigators:

1. Is a tablet ‘dashboard’ application the proper tool to present multiple data streams to classroom teachers to assist in increasing classroom learning? If yes, what variables should be displayed and visualized?
2. Should data visualizations be dynamic (live updating with inbound data), interactive (affording the user the ability to deep dive into data), or both?
3. Does the visualization of in-bound data streams (from transformative games) assist in classroom teaching?
4. Is it possible to customize the gaming experience by group or individual students?

2 Theoretical Frameworks

This research combines several theoretical frameworks with respect to the design of a teacher dashboard application: Participatory Design, Activity Theory, and Conceptual Design. In addition, the concept of affordances is utilized to help drive the resulting design decisions. Participatory Design is an emerging area for instructional design and technology that calls for more empirical work. For example, Könings, Brand-Gruwel, & Van Merriënboer [6] used a participatory design approach working with secondary teachers and students in a co-design sctivity that emphasized *perspective*. Investigators reported that results from exploratory work were encouraging in that a participatory design approach allowed instructional designers and teachers to gain insights about students learning to facilitate improvement to classroom practices. Likewise, Activity Theory has been a part of the instructional design and technology vernacular for close to 15 years. Jonassen and Rohrer-Murphy [7] provided a seminal piece to articulate how Activity Theory can frame the design of constructivist learning environments (CLE). The proposed teacher dashboard is envisioned as an integral component to an overall CLE that also includes interactive assessments and learning games being developed by investigators and detailed in extant efforts [8].

2.1 Participatory Design

Participatory Design was initially used in the design and development of computer applications and systems in Scandinavia and was referred to as Cooperative Design [9]. As the theory moved westward to the US, the term Participatory replaced Cooperative due to the nature of the first applications in business and the need to stress the vested interest of the participants.

The primary goal of PD is to help provide greater consideration and understanding of the needs and wants of system users, also known as stakeholders. In the context of this research, PD was used to carefully explore, extract, and integrate the needs, perspectives, and affordances of classroom teachers in hopes of increasing the likelihood of deployment and adoption of [The Teacher Dashboard].

PD can be applied using a number of different developmental / idea generation methods. This research utilized several popular PD methodologies including: brainstorming exercises, card sorting, group affinity diagraming, rapid paper prototyping, wireframe walkthroughs, and preferences testing. [10,11]

2.2 Activity Theory & Contextual Design

Activity Theory (AT) is based in part on the work of Vygotsky, Leont'ev, and has been expanded upon by Yro Engström [12,13,14]. In essence, activity theory states that human beings interact with their environment via situations mediated by tools. Through mediation these situations create experiences. "This notion is usually portrayed by what has come to be known as the mediation model of human interactions with the environment," [15].

In this research, AT is used to frame the design decisions of the tools (applications) the students and teachers use in the classroom and contextual inquiry uncovers the affordances and needs of the stakeholders.

In addition to utilizing PD to uncover application features and uses, and AT to drive research questions, particular attention was paid to several key principles of contextual inquiry, sometimes referred to as Contextual Design (CD), as it relates to HCI. Contextual design is a defined user-centered design process, which provides methods to assist in data collection and analysis. [11] CD is built upon methods and theories from several disclplines including anthropology, psychology, and design. CD is considered one of several "user-centered" design approaches to systems design. [11] CD is driven by five (5) key principles summarized in Table 1 below (see [11] for a complete description of CD including the five principles):

Table 1. Description of five principles of Contextual Design.

Principle	Description
Principle 1	System design must support and extend users' work practice
Principle 2	People are experts at what they do- but are unable to articulate their own work practice
Principle 3	Good design requires partnership and participation with users
Principle 4	Good design is systemic
Principle 5	Design depends on explicit representations

2.3 Technological Affordances and Design Affinities

An affordance can be defined as the qualities of a system, which allow interaction by any given stakeholder. Psychologist James J. Gibson initially introduced the term affordance in a 1977 article [16] and again in his book *The Ecological Approach to Visual Perception* [17]. In 1988, Donald Norman applied the term in the context of software and interface design. This application expanded the initial definition to include those designed elements that provide for the ease of use by a stakeholder [18].

Large amounts of qualitative data are collected when implementing the PD methods described above, and analysis proves challenging for some. This research applied the KJ Method first described by Jiro Kawakita [19]. Kawakita devised the KJ-Method when standard anthropological techniques proved inadequate to analyze the massive amounts of qualitative data he had amassed during research for the Japanese Government. Business researchers and strategists incorporate KJ-Method when they generate affinity diagrams. Essentially the KJ Method assists with data analysis by grouping, organizing, and sorting data into reoccurring thematic areas [19]. The KJ-Method assists by analyzing large data sets for emergent thematic areas, essentially creating what some refer to as affinity tables or diagrams. In the case of this research, data was assembled into a spreadsheet and analyzed and grouped into thematic areas during an iterative process.

3 Methodology

Utilizing a model of PD, the researchers worked in semi-structured workshops, across three (unique) encounters, or what the authors call phases, with six mathematics teachers, to explore the design of a new teacher dashboard application to accompany a current in-classroom mathematics application. The workshops were structured into three phases: brainstorming, card sorting, and group discussion of ideas generated.

The purpose of these workshop sessions was to uncover and identify key data streams, preferred data visualizations, and feature requirements along with their level of hierarchical importance for the teachers. Several streams of live-data from the in-classroom application are available to present to the teacher; however, not all may be important at any given moment. In turn, these results would inform the design decisions as well as the information architecture and interaction design of the resulting dashboard application.

This research relied on 3 unique phases of PD, each iterating on the findings of the prior phase to refine, clarify, and apply the emerging data. These phases are briefly described in Table 2.

Table 2. Description of three phase approach.

Phase	Description
Phase I	Identify data-streams of extreme importance to classroom teachers
Phase II	Gather initial reactions to wireframe prototype while refining necessary data-streams and key features
Phase III	Gain insight into preferred data visualizations and interaction with data preferences

Participants. Participants in the participatory design session included six middle school teachers, two each from grades 6, 7, and 8, and an instructional technology resource teacher (ITRT). The teachers were recruited from two middle schools in southwest Virginia and are participating in the broader three-year project to enhance pre-algebraic mathematics instruction and learning. Teachers were all female and had at least five years of experience in the classroom. The session was led by the authors and graduate student in visual design and communication. The initial session was held on June 12, 2012 and lasted less than two hours. Additional sessions were held in October of 2012 and February of 2013.

3.1 Phase I, Participatory Design

Goals. Generate ideas for content and design, gain a better understanding of our target audience, and gather insights to create an effective application.

Data Sources. Phase I of the workshop asked the teachers to identify various types of data they would like to see from the mathematics application on a teacher dashboard. These results were written down on Post-It notes and scattered across a whiteboard. This initial phase resulted in over 150 unique and novel ideas.

Phase I was conduced immediately following sessions that were reviewing a Candy Facoty, and as a result throughout the PD session it was revealed the teacher participants were having a difficult time detaching from the currently deployed mathematics application and the development of the teacher dashboard application. Therefore, the results began to reveal a shifted focus of the PD session that incorporated ideas and suggestions for the deployed mathematics application. In the end, all of the data proved valuable to the design process and is a testament to allowing free-form PD sessions to progress organically.

Data Analysis. Incorporating the KJ method, read above, three unique areas of emergent ideas were uncovered, and referred to as Phase I-Step A: dashboard application, mathematics application, and relevance to both applications. (See Figure 1) Once these three areas were identified, the initial 150 ideas from the workshop participants were divided amongst these three areas.

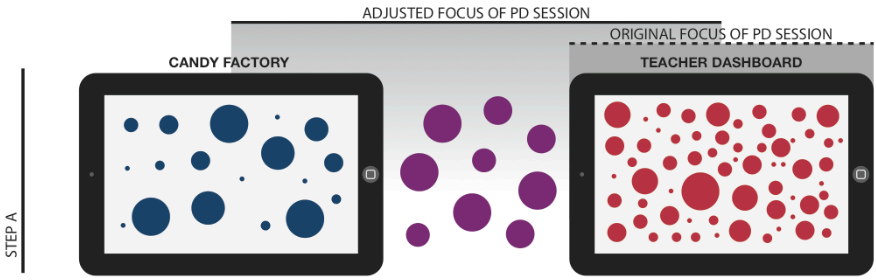


Fig. 1. Phase I, Step A participatory design results. Each circle represents a unique idea, with the circle diameter representing the number of times the unique idea was discussed.

Upon further examination of the results from Phase I-Step A, and continual iterative application of the KJ method, the researchers began to see similarities and trending ideas, which led to combination of like ideas resulting in 53 unique and novel ideas which were referred to as Phase I-Step B. This regrouping of ideas then necessitated resorting into new categories (See Figure 2).

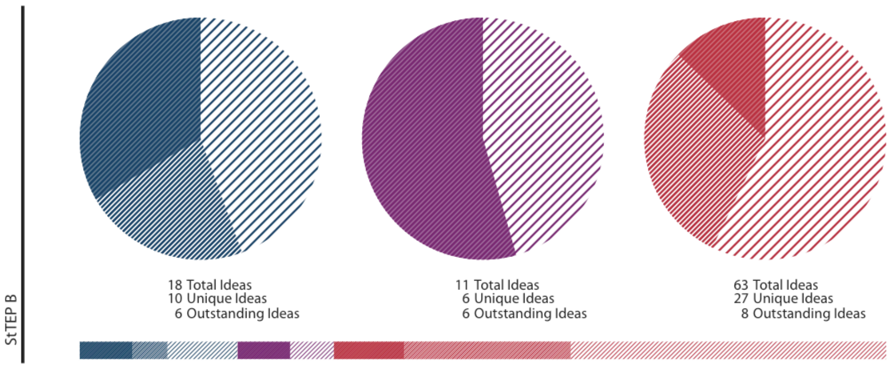


Fig. 2. Phase I, Step B participatory design results. Applying the KJ Method to distill new catagorical representations of data.

Starting with the self-identified categories from workshop participants, the researchers began to reorganize the results from Step B, which resulted in a group of new categories emerging referred to as Phase I-Step C (See Figure 3). The resulting categories were: design, hints & help, student profiles / logins, game play, data to be collected, data to be sent, data visualization, and printout-PDF & data sharing. It is these resulting categories that helped to influence the design of the dashboard prototype.

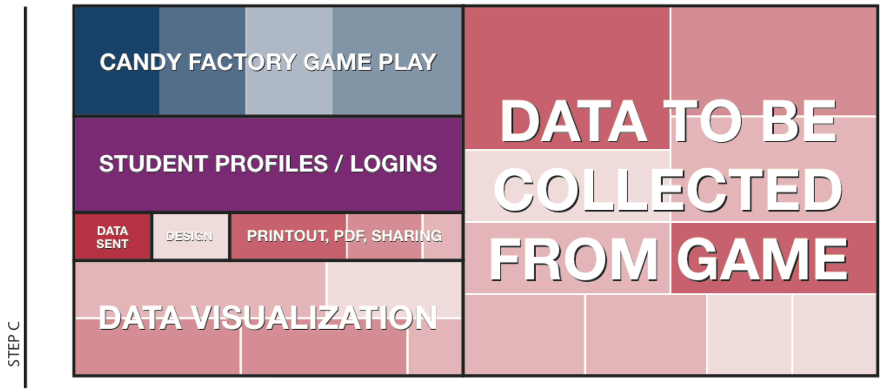


Fig. 3. Phase I, Step B participatory design results. Applying the KJ Method to distill new catagorical representations of data.

A method of refinement and categorizing was applied which lead to the following categorizations of findings:

1. Candy Factory Gameplay
   a. Student Profiles and Login
2. Data to be Collected
   a. Data Sent
   b. Data over time
   c. Classroom Level Data
   d. Student Level Data
   e. Task Level Data
   f. Real Time Data
   g. Fractions students…
   h. Trophies…
   i. Time Spent
   j. Accuracy
3. Data Visualization
   a. Design
   b. Printout, PDF & Data Sharing
   c. Graphs & Charts
   d. Classroom Comparison
   e. Color Coded Data
   f. Data Sorting

3.2 Phase II, Participatory Design

Goals. Gather feedback on the initial wireframe prototype including observational data of interactions by classroom teachers.

Data Sources. Phase II involved several step. First, Step 1- card sorting, a method of categorizing ideas and data was incorporated. Teachers were asked to revisit their ideas from Phase I and group these results into several self-identified categories. Second, the teachers were asked to interact with a wireframe prototype of the Dashboard App designed after analysis of data acquired in Phase I.

Data Analysis. Step 1 resulted in nine (9) unique categories being generated by the teachers: color coded data, hints, logins, rewards, class data, data over time, time on-task per level, design ideas, and positive reinforcement. These categories are being used as determining factors in the next iterative phase of design. The second step, wireframe interaction, produced several ideas about data visualization and the lack of connectedness between teachers and visual data. This discovery led to Phase III. Using the results from Phase I- Step C, the researchers and designers were able to work together to wireframe a prototype of the teacher dashboard application. The results from PD session Phase II and researcher Step B influenced the information architecture and content placement for the teacher dashboard. For example, teachers indicated they wanted quick access to how their class was performing while using the mathematics application. This resulted in the 'Overview' page that contains two key data streams: accuracy and problem solving speed (See Figure 4). These graphs provide an instant snapshot, using live data, of how students were performing using the app and immediately inform the teacher if adjustments need to be made.

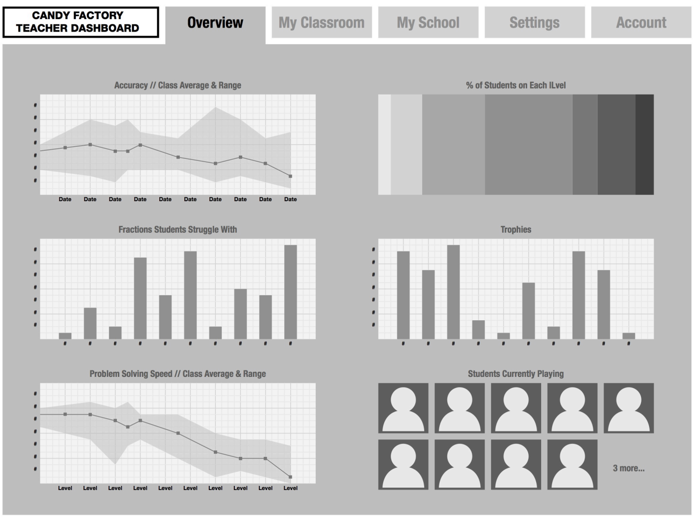


Fig. 4. Overview wireframe of the Teacher Dashboard App, design decisions were driven by the results of participatory data obtained from the teacher stakeholders. Note the visualizations of data per class and students currently engaging with the game.

Teachers also indicated they wanted to be able to 'dive' into a student's record. This resulted in the student detail page (See Figure 5). Details on this page are updated in real-time and charted for quick visual information to assist in decision-making regarding the student's performance.

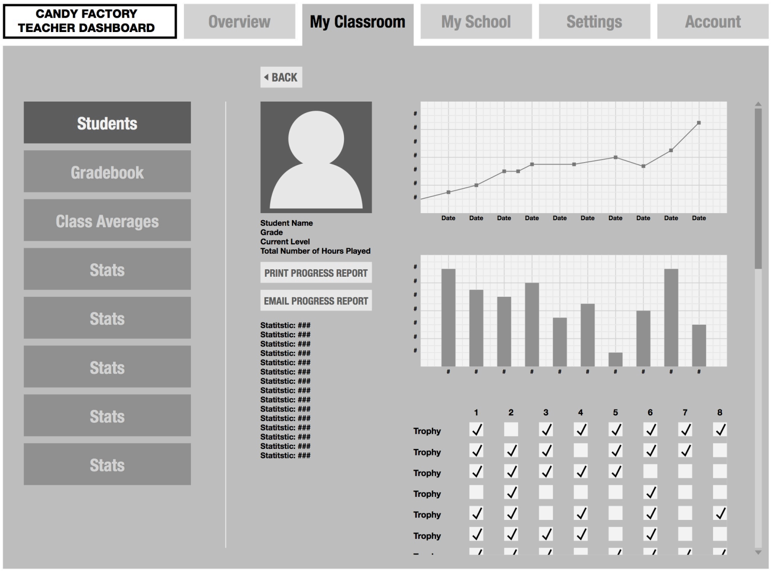


Fig. 5. Student detail page. Note selected data visualizations teachers requested.

Another discovery made through the PD session was teachers wanted the ability to compare their class with others in their school. This feature may have escaped attention had the PD session not occurred.

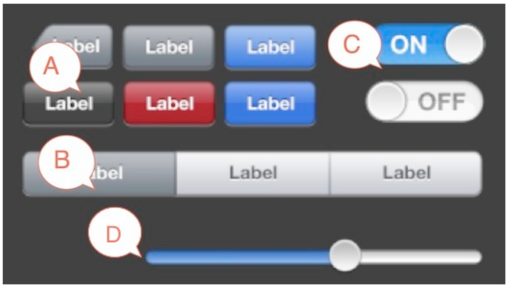
3.3 Phase III, Participatory Design

Goals. Discover primary data interactions and gestures teachers prefer.

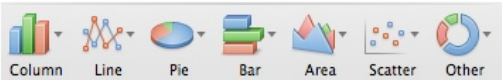
Data Sources. Phase III asked participants to complete a short survey to determine stakeholder preferences with regard to data interactions and interface elements as well as gestures teachers prefer.

Data Analysis. Analysis revealed that teachers prefer to interact with toggle interface elements and visualizations that contained line and column graphs for data visualizations (See Table 3).

Table 3. Results of survey with regard to interface elements and data visualizations.



What interface elements would be the easiest and fastest to use while teaching? (n=6)
C=5
D=3
B=2
A=1



What graph type(s) would be the easiest and fastest to use while teaching? (n=6)
Line=5
Column=4
Pie=2
Bar=2
Scatter=1
Area=0
Donut/Other=0

4 Warrants for Claims

The results of this initial research indicate that the workshop participants were interested in assisting in the design of the dashboard application; however, as discussed previously, since they had been engaged with the mathematics application they still wanted to provide additional feedback regarding the app. This was unexpected, but in the end, provided another layer of rich data.

By utilizing the KJ Method and distilling the PD data, we were able to hone necessary data streams and place them into an hierarchical information architecture. The hierarchy was determined by reanalyzing the qualitative data and initial ideas and categories from Phase I of the PD workshop, to determine the levels of importance assigned to each individual data stream. In turn, the resulting application categories, based on those of the teachers in Phase I, drove the design of the dashboard application. This sorting and categorical identification allowed the designers to better understand the innate affordances perceived by teachers and better design the teacher dashboard.

Revisiting our research questions, we discovered several items of importance, as well as their hierarchical position in the Dashboard App. Teachers expressed three (3) main features for the dashboard, detailed in Table 4.

1. What essential, real-time data do middle school mathematics teachers need to make sound, intentional decisions in the classroom within the scope of the larger project?

2. How can data from student performance on educational game-based learning be experienced to maximize decision-making processes?
3. How can such data representations be enhanced through multimodal interaction (sound, visuals, motion, haptics, etc.) for analytical purposes?

Table 4. Uncovered Feature set.

Feature 1	Application must have the ability to add and remove students to the classroom roster, as well as easily transfer a student to another classroom.
Feature 2	Application must have the ability to customize the gaming experience across 2 main divisions: the entire classroom, and individualized customized groups determined by the classroom teacher, ie. Students who all have trouble with similar probems are automatically grouped together by the dashboard.
Feature 2	Application must utilize the standard iOS interface guidelines, as teachers want to interact with visualized data through touch, pinch, and flick gestures.

5 Discussion and Significance

While the initial prototype of the teacher dashboard is still under development, the results of this research have had a large impact on the design decisions being made. Through analysis of the PD data, combined with design expertise, the unique design affordances of mathematics teachers was able to be uncovered. The application designers were able to respond to the needs and desires of the teachers only by analyzing the PD data. Without the PD sessions, the application dashboard would have been created by designers void of understanding the affordances and feature requests of the teachers.

Allowing PD session data to drive design decisions is not new; however, uncovering design affordances of middle-school mathmatics teachers in combination with driving design decisions and selection of data visualizations can be. For example, application designers might not have selected toggle interface elements had it not been for the PD session and the results of the survey. The importance of Participatory Design can not be overlooked. With regards to data visualization, designers may not have selected line and column graphs had it this not been uncovered during discussion and discovery at the participatory design sessions.

In addition to the discovered affordances, one of the most important discoveries is the selection of data visualizations according to teacher preferance. Teachers prefer graphs that are made of lines and columns and desire to interact with these data visualizations using pinch, swipe, and flick gestures of the iOS system. Through this discovery the design team has been able to explore alternative visualizations of the complex data being supplied from the CandyFactory App, and create visuals that teachers can quickly understand and act upon.

Moreover, the results of this research could be attractive to funding agencies such as the National Science Foundation (BIGDATA) and the Institute of Education Sciences (learning analytics, educational technology) that are increasingly aware of the need to respond to the data deluge. The added impact of this work is that focus will be placed on underrepresented, under-resourced school districts in southwest Virginia that have documented needs for improvement in mathematics achievement scores.

6 Conclusion

By incorporating discoveries from mathematics teachers during a PD session, designers and programmers are better able to present live streams of data to mathematics teachers. Further research will include a fourth PD session during which teachers will interact with a high-fidelity wireframe prototype and begin to assist in more visualization of the application's data streams. Ultimately, the researchers hope these visualizations and the resulting dashboard application can be applied to a broader range of student data.

Acknowledgments. This material is based on work supported by the National Science Foundation (NSF) under Grant No. DRL-1118571, and the Scieneering Undergraduate Research Program, the Institute for Creativity, Arts, and Technology (ICAT), and the Institute for Society, Culture, and Environment (ISCE) at Virginia Tech. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of sponsoring organizations. The Learning Transformation Research Group at Virginia Tech includes the authors and a talented team of co-investigators (Kirby Deater-Deckard, Anderson Norton, Osman Balci), and graduate and undergraduate research assistants.

References

1. National Science Foundation, NSF Task Force on Cyberlearning. (2008). *Fostering Learning in the Networked World: The Cyberlearning Opportunity and Challenge* (NSF Report nsf08204). Retrieved from http://www.nsf.gov/publications/pub_summ.jsp?ods_key=nsf08204
2. President's Council of Advisors on Science and Technology. (2010). *Prepare and Inspire: K-12 Educations in Science, Technology, Engineering, and Math (STEM) for America's Future*. http://www.whitehouse.gov/administration/eop/ostp/pcast/docsreports
3. U.S. Department of Education (2010). *Transforming American Education Learning Powered by Technology*. http://www.ed.gov/sites/default/files/netp2010-execsumm.pdf
4. Evans, M. A., Norton, A., Chang, M., Deater-Deckard, K., & Balci, O. (2013). Youth and video games. Zeitschrift für Psychologie, 221(2), 98-106.

5. Evans, M.A., Pruett, J.*, Chang, M., & Nino, M.* (in press, 2013 publication date). Designing personalized learning products for middle school mathematics: The case for networked learning games. To be published in the *Journal for Educational Technology Systems*.
6. Könings, K. D., Brand-Gruwel, S., & Van Merriënboer, J. J. G. (2010). An approach to participatory instructional design in secondary education: an exploratory study. *Educational Research, 52*(1), 45-59.
7. Jonassen, D., & Rohrer-Murphy, L. (1999). Activity theory as a framework for designing constructivist learning environments. *Educational Technology Research & Development, 47*(1), 217-234.
8. Norton, A., Wilkins, J. L. M., Evans, M. A., Deater-Deckard, K., Balci, O., Chang, M. (2014). Transcending part-whole conceptions of fractions. *Mathematics Teaching in the Middle School, 19*(6), 352.
9. Bødker, K., Kensing, F., and Simonsen, J. (2004). *Participatory IT design: Designing for business and workplace realities*. Cambridge, MA, USA: MIT Press.
10. Muller, M. J. (2003). Participatory design: the third space in HCI. *Human-computer interaction: Development process*, 1051-1068.
11. Holtzblatt, Karen and Beyer, Hugh R. (2013). Contextual Design. In: Soegaard, Mads and Dam, Rikke Friis (eds.), The Encyclopedia of Human-Computer Interaction, 2nd Ed.. Aarhus, Denmark: The Interaction Design Foundation. Available online at http://www.interaction-design.org/encyclopedia/contextual_design.html
12. Van der Veer, R. (2007). Vygotsky in context: 1900-1935. In H. Daniels, M. Cole, & J. V. Wertsch. *The Cambridge companion to Vygotsky* (pp. 21-49). New York, NY: Cambridge University Press.
13. Leont'ev, A. *Problems of the development of mind*. English translation, Progress Press, 1981, Moscow. (Russian original 1947)
14. Engeström, Yrjö; Miettinen, Reijo; Punamäki, Raija-Leena (1999). *Perspectives on Activity Theory*. Cambridge University Press.
15. Mwanza, D. (2001). *Where Theory meets Practice: A Case for an Activity Theory based Methodology to guide Computer System Design. INTERACT'2001*, Toyko, Japan.
16. Gibson, James. J. (1977), The Theory of Affordances. In *Perceiving, Acting, and Knowing,* Eds. Robert Shaw and John Bransford.
17. Gibson, James. J. (1979), *The Ecological Approach to Visual Perception*.
18. Norman, Donald A. (1999). Affordances, Conventions and Design. *Interactions* 6(3):38-43, May 1999, ACM Press.
19. Kawakita, J. (1982). The Original KJ method . *Kawakita Research Institute, Tokyo*.