Go Math! How research anchors new mobile learning environments

The Family Math Project Team (April Alexander, Kristen Pilner Blair, Shelley Goldman, Osvaldo Jimenez, Masataka Nakaue, Roy Pea, Andrew Russell)
Stanford University
ojimenez@stanford.edu

Abstract

A reciprocal research and design process (RR&D) became central to the development of mobile learning environments for families. Go Math! applications were developed to support families in the situations they face in their daily activities where problem solving involves mathematics. The foundation of the RR&D process is that it is effective for synthesizing design and development choices with consideration of the results of basic research on mathematics in everyday life, the voice of users, the social context of use, and mobile affordances. The RR&D process is described, and two mobile mathematics applications illustrate how the process maintains fidelity among related research, the development of design criteria, and user voice and practice. We consider the process important in the development of mobile learning environments.

Introduction

The findings of a "basic" research study for the Family Math project anchored the development of mobile learning environments by anchoring design criteria, development considerations and trade-off spaces. In the basic study, we interviewed 74 people in 23 families and identified the many mathematical problem-solving activities they engaged in [1]. Our data set was filled with the narratives and conversations of our participants. Throughout data analysis, we strove to keep the first person voices of our participants, and whether we were conducting quantitative or qualitative analyses, we continually had the participants speak to us by returning to our primary data: video recordings of the interviews and family activities. When we embarked on the research, we sought to identify the contexts, activities, and resources brought to bear on learning mathematics in families. Our hope was that our findings would lead to the creation of resources to support mathematical practices of daily life. The findings were meant to be the foundation for design and development efforts.

When we began to shift towards development, we culled our results, and engaged in a process to keep fidelity with our findings, and to have our participating family members inform our design. The Go MATH! mobile applications we have developed are the result of the reciprocal research and development process (RR&D) we developed that facilitated interaction at the nexus of basic research findings, the voices of our research participants, and our user test informants. Even the idea that we would develop environments for mobile platforms came from our families, who told us about all of the math involved practices they engaged while they were "on the go" each day. From the first ideation activities, the design and development process drew on what we learned about the family as a setting for mathematical activity and the imperative that any development would need to build on and support family practices to help further extend the family as a social setting for mathematical activity and learning.

Go Math! mobile applications were designed to support collaborative activity and encourage mathematical talk and activity among family members. For example, in *Go Play Ball* children and parents use mobile devices to calculate youngsters' statistics after each game, such as their on-base percentage, and to use graphs to track progress over time for comparison to major league players. *Go Road Trip* provides an infrastructure for mathematizing traditional family car activities, such as guessing the time of arrival at a destination, playing math/road games, and maintaining records of family road trip activities. *Go Route Planne*r is a tool to help families record data about different routes between common destinations, such as school to the soccer field. Plotting the time data collected over multiple trips helps the family decide the best route at a given time of day. The mobile platform was chosen because family members carried mobile phones with them in daily activity, making use of them anytime, anywhere [2]. We also hoped to capitalize on the existing social uses of mobile phones for learning [3] [4].

Go Math! The Reciprocal Research and Design Process and its impact on mobile environment development

A major tenet of the Reciprocal Research and Development process (RR&D) is that the people and situations for which we are designing inform it. We consider the daily problem solving situations of the families as the primary forces behind the use and efficacy of environments once they are *in situ*, therefore we employ a reciprocal and collaborative RR&D process that takes the voice of our participants, the affordances of the mobile platform, and the results we get from user testing. We relied on what our participants' accounts of their mathematical activity told us and derived our design mission and criteria from these results. These collaborative and research-based methods evolved traditions that preceded this hybrid development effort. In our case, practices find their roots in traditions of participatory design and user studies in computer science, and design research in the field of education. The participatory design movement has spawned an array of methods, processes and orientations for involving multiple stakeholders and end users in the design process [5] [6] [7] [8]. In computer science there is concern for user-centered design [8]; in education the ideas have taken hold at the intersections of research on learning and the design of curriculum [9] [10] [11] [12] and assessments [13], and in K-12 technology for children [5] [14] [11] [15]. The Family Math research and collaborative development process draws on the participatory tradition, yet is differentiated from it by attention to the familial environment, with an emphasis on an elevated role for the voices and feedback of parents and children in platform choice, design criteria, and effectiveness of the environments in their situated practices.

We used the RR&D process to drive the design and development to a "third space" in technology [16] as well as learning [17]. Third space is a synergistic place for imagining new ideas and solutions—a place for vision that comes from multiple perspectives and places, and dominant and non-dominant factors or positions all have equal sway, making hybrid solutions possible. In our case, it is the place where the reflective and reflexive nature of the RR&D process can be realized. It is the nexus for negotiating and achieving insights about the institution and cultural settings for the designs, the specific situations for use, the assumptions about family math practices, and mobile affordances and constraints.

Attention to the reciprocal research and design process was instantiated in several ways. Our team conducted the basic research phase that led to designs. We interviewed families, videotaping the interviews and tasks. We conducted various analyses of the data set, and had results that were vetted for relevance to the mobile design process. We retained access to our primary video data sources to constantly capture, listen to, and compare the voices of our participants and users to our design and development decisions. We saw this reflexive interrogation of the findings from basic research, user voice and feedback, and the technological considerations. For example: Our goal was to design environments to support more interaction with math in families, and the research results indicated that it would be beneficial to help families accomplish daily life problem solving while they were *on the go* and *in situ*. This finding connected directly to the decision to develop for mobile applications. With mobile capabilities in mind, the team next engaged a review process to summarize the areas of relevant findings, and develop the design mission, design criteria, and a list of considerations and trade-off spaces. Research results and direct instances from the primary data were extracted and examined as each design decision was made.

We illustrate the RR&D process in the following ways. First, we highlight the findings of our initial interview study that had implications for the *Go Math!* development and research process. Second, we show the design criteria and trade-off space considerations we derived from a review of the findings and consideration of the mobile design space. Third, we illustrate the reciprocal nature of the process through examples from our mobile applications. And last, we present a short discussion of the RR&D process and its implications for the development of mobile learning environments.

The contributing research findings

The Family Math research findings in three areas were applicable to the Go Math! mobile designs: (1) the characteristics of problem solving in the family; (2), the participatory nature of activity in the family and, subsequently, of mathematics; and (3), the significant differences between math at home and math in the school.

(1) The nature of problem solving had specific characteristics. The first finding was that, in the family, life problems lead the math. Life problems are context and situation determined. The problems to be solved can be complex, involve many steps, and often are nested inside larger problems as well as leading to

other problems. Knowledge and solutions derived must also align with situations and real constraints. People generally conceive of their problems and secondarily consider how to solve them and then when to use math. Math in the family also requires people to evaluate their own solutions, and people have to decide if their solutions are correct, if the correct solution is really relevant or appropriate to the particularities of the situation. Values steered the problem definitions, problem solutions, and the imperatives for solutions [18]. Values answer the "why bother to solve this problem" question for family members. They also lead to many of the "how" questions. When families spoke about their problem solving strategies and gave examples of the kinds of problems that arose in their lives, family members consistently talked about what they valued. They talked about what was important to them when they talked about their decisions, social activities, projects, and relationships. What stood out as unique in family problem solving was the role their values played in structuring their problem solving. They brought social and cultural norms to the forefront of problem solving.

(2) Problem solving practices in the home were social, involving multiple people and tools as resources. Stories of mathematical activities in the home revealed how problem solving was a social activity, involving multiple people coordinating activities over multiple instances or contexts, and with many chances for revision and success. The family members were often chosen to collaborate in problem solving practices based on need for one family member's expertise (e.g., a child asking a parent for help in solving a problem), or when family members found what they believed to be important learning opportunities for their family. Although we had asked the interviewers to tell us about their own experience, most of the stories we had involved more than one person, and those events as recounted across family members also tended to be the most lively and rich in mathematical discourse.

(3) We found several distinctions between how people talked about math use at home and at school. [19] School mathematics stories were often structured around mathematics as an end in itself, involving external evaluation. Home enabled a wide range of allowable solution methods, resources and attempts at solutions. People cited examples of mathematics being used to support one's sense of personal and of social responsibility (e.g., being fiscally responsible, caring for others, and desire for making family decisions). We also saw that math was an integrated part of fun hobbies and activities. In low-risk settings like a family car ride, parents and children engaged in playful problem posing and problem-solving activities together. In these instances, mathematics was the means to a valued end.

The three categories of findings—(1) that the problem space in the family was complex, related to values, issues, and desires, (2) that mathematics was most often socially distributed, and (3) that family math offered an entirely different constellation of problems and structures for success and identity-building—became key factors to become embedded in design for mobile math environments.

From Research to Ideation and Development

The translation from research findings to design considerations and development engaged the team in a series of specific steps and activities: starting with the interrogation of the research, to ideation, to working on functionality and features, to user testing and field research, to revisions, and finally to a restart of the process. The process began with a review of all of basic research findings and literature in the field. The team also looked specifically at "relevant" cases from data by returning to primary video of the sessions with families. Of specific interest were highly referenced contexts for mathematical problem-solving that many families mentioned (e.g., shopping, budgeting, home improvements, and times they spend in leisure). For each, we analyzed the math up to the level of pre-algebra that was covered.

The research analysis helped us develop our mission for "on the go" mobile tools and to establish design principles, that organized the possible development space and defined features of the environments.

We deduced that the mobile environments needed to be:

1. Situation-driven
2. Promoting enjoyment of mathematics
3. Demonstrating the value of mathematizing experience by helping parents and kids discover the math in everyday situations and contexts
4. Driven by values (if people do not see it as an important problem, they will not engage it)
5. Reinforcing the family as a social unit of mathematical activity and learning
6. A complement to school: math activities in the applications are complementary and supportive of school math up to first year algebra

7. Designed for mobile affordances: they are not simply miniature applications but use the collaborative/social capabilities of mobiles
8. Based on and relevant to results and the charter for Family Math

The findings and a study of narrative accounts of our participants also helped us develop a set of questions we answered regularly during design and when we reached development junctures:

• Does the environment adhere to a problem solving orientation?
• Is the application encouraging collaboration and promoting social arrangements and conversations that are either intergenerational or peer-based?
• Is it reinforcing or making familial–community–school links possible?
• Is it fostering the ability of children and families to be successful in bringing math to their daily activities and problem solving?
• Have we checked for feedback from middle school children and their families?
• Is it supporting users and giving them control over some aspect of their activities?
• Are we developing in user-centered ways?

The complexity of the design criteria led to a decision to experiment by designing a series of mobile math applications that would instantiate different combinations of the design criteria. For example, one environment, *Go Play Ball*, would be in support of peer-based activity; another, *Go Road Trip*, would strive to support math in an intergenerational activity setting.. It also led us to examine the possible mobile platforms. We reflected on the extra resources we needed for different technological development tasks, such as money, additional partnerships, programming capability.

We moved into a process for brainstorming and storyboarding of possible applications that were based on mobile platforms, our design principles, and trade-off spaces. We rated the difficulty for our development efforts and narrowed the choices to a priority list of seven applications we could eventually create.

We did a round of user-tests with our top seven applications as paper prototypes. Correspondingly, we made choices about our development platform based on the mobile access potential of our participant families. The ideas for priorities came from negotiations that considered any application concept, platform, development capability, and participant feedback data. For example, we looked at the trade-off between the costs of different mobile platforms and our agenda for access.

There were many trade-off conflicts needing resolution. Each had implications for the development of the environments and for the kind of learning environments they would support [20]. The trade-offs included: in supporting social activity, decisions needed to be reached about whether "how much social" would be built into an application. Would this be an application that worked across single or multiple users and multiple mobile devices? Would any particular application be self-contained or networked? Would an application be used in the short term or the long term, and what capability would be needed for either choice? Would there be record-keeping or communication with the server as part of supporting the learning goals we had set?

Decisions on trade-off spaces came after consideration of findings, careful attention to how family members interacted, and considerations of our team's ability and resources for reaching development goals. Remaining true to the RR&D process and experimenting with it, we started with the development of the two applications that would allow us to run and evaluate the full process cycle and have applications in new participant study cycles.

The RR&D process enabled the team to stay involved with design iterations for improvement of the mobile applications and continued knowledge fed back to the research knowledge base. Data collection, analysis, and redesign was ongoing in concert with development activities. Two studies, one with a complete round of the RR&D process (*Go Play Ball*), and one in progress (*Go Road Trip*) provide examples.

Two Mobile Math Applications

The resulting mobile environments are compelling instantiations of reciprocal research and development process. We present two environments and tell their development story through the RR&D lens by examining the design criteria and trade-off dimensions that were culled based on research, and show how the process resulted in development, user-testing priorities, and revisions. We present two examples of mobile applications, using each to highlight the contributions of the RR&D process.

Go Play Ball

From Research to Mobile Application. Many families from the study identified sports as a time that they used math, both in keeping score in games they were watching and in games that they played themselves. Our team recognized that baseball and softball offered an excellent opportunity for families to use ratios and percentages as well as graphical representations to enrich their enjoyment of the game and to help them track their own improvement.

Go Play Ball allows players to enter information about their little league *performances*. The players first enter general information about the game such as date and opponent. Then, they are taken through a screen that prompts them for the information for Batting Average and On-Base Percentage while being shown the process for the resulting computations. Finally, the players enter runs scored, how many hits they made and whether they won or lost the game. At any time, the players can track their progress by viewing graphs or charts about the individual statistics.

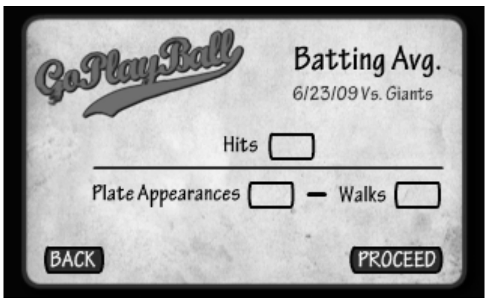

Figure 1. Batting Average Representation

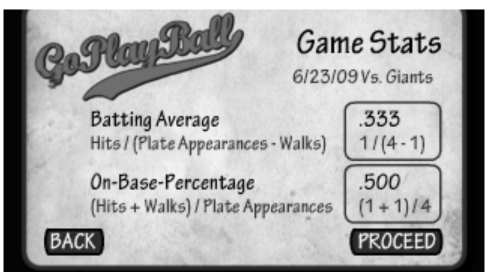

Figure 2: Average vs. On Base Percentage

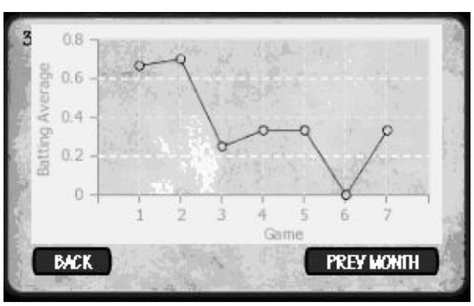

Figure 3: Graphing Batting Average

Go Play Ball was designed with our research results in mind. It is situation-driven around individual baseball and softball games as well as the season as a whole. By providing an environment for keeping and records of progress and calculating player statistics, players and their families are able to see and interact with the multiple ways that math is used in the game with attention to their personal stats and those of their favorite professional players. It is a context- and situation-specific application.

Go Play Ball evolved based on real usage constraints. The original design of the application was for it to be used by the players at their games. The development team thought it would allow for greater accuracy of record keeping. Unfortunately, in our study, the team organization we partnered with asked that the players not bring the phone to games in order to prevent competition among them.

Initially we envisioned the application being used socially, both in the family and among peers. However, indications from our research findings had us concerned about competition among the young players. Once the Little League Team also indicated concern about competition among the players, we changed the ways that the youngsters could compare baseball statistics. Rather than allowing teammates to compare scores, but to maintain the math opportunities fostered by the comparisons, we created a feature that linked our youth to player statistics for one of their favorite Major League Baseball players. We would have to see how this removal of competition affected the use and satisfaction with the application.

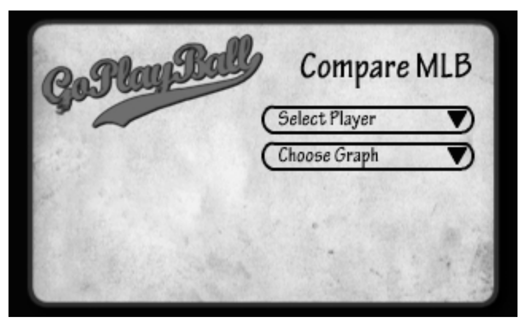

Figure 4: Comparing Major League Statistics

User Study Research. Six families from a predominantly low-income neighborhood of Boston used the *Go Play Ball* application for 3-4 weeks of the little league baseball season. User studies included:

• Pre and post-surveys that included baseball statistics questions, questions about attitudes towards mathematics, and questions about family participation little league activities.

• User interface interviews and surveys that provided insight into user's experiences when navigating through the application.

• Logging information, including the time and duration of access, and the data participants entered and plotted, and the number and types of comparisons with professional players.

Analysis. In *Go Play Ball* we saw how students understood the math behind their baseball performances and the performances of professional players. Results indicated that the little leaguers developed in their understanding of how batting averages were established and how they changed in relation to number of games played and the number of at-bats.

Across applications, a focus of our analyses is on how the mobile applications supported activity and conversations among family members. In the *Go Play Ball* study, we found that mathematical problem solving was distributed among family members. Results from one of our surveys demonstrated that the little leaguers discussed their little league activities 3-10 times a week, with family members including parents, grandparents, siblings and extended family members. Each player had a family member who went to games and discussed their play. The *Go Play Ball* application positively mediated collaborative activity across family members in relation to baseball statistics. Results also revealed that orientation to the mobile phone use was consistent with familial interaction patterns prior to introduction of the mobiles [21], creating additional opportunities for tracking and analyzing baseball statistics. The applications did not facilitate player to player conversations, and that may have been caused by the league's reluctance to allow the mobile at the game or the fact that the application did not support player to player statistic comparisons.

The findings from this round are being revisited to determine what changes will be made for the upcoming round for the next baseball season.

Go Road Trip

Description of the mobile Application. The inspirations for *Go Road Trip* were specific instances in which we found families that provided scenarios for their children to think about distances. One family played a game in which the daughter in the family wondered whether or not she could hold her breath while travelling the distance over the Golden Gate Bridge, and the family together decided they would have to drive faster to make it possible for her to win the challenge. The challenge related to the distance and time problems and was a way for the family to pass time in the car.

Figure 5: Allowing multiple players to guess

Go Road Trip is a mobile application designed to promote math awareness and fun with math during long road trips for families. The application is meant to help solve the often asked questions by the children of "are we there yet? Initially designed as a trip estimator tool, *Go Road Trip* has evolved into an application that families can play constantly throughout a trip. Keeping in line with our research based design criteria, the mini games are intended to draw on game-like play directly rooted to the car context. They are meant to be inter-generational, and to be played across all family members in the vehicle.

Go Road Trip is currently a set of nine mathematics games designed for families to play while traveling in the car. A central estimation game that involves multiple family members in a rate/time/distance problem lasts for the duration of the car trip. Each family member enters a guess about the time of arrival at the destination, and tools such as route plotting help family members generate their estimations. During the trip, status updates indicate the percentage of the trip completed, the number of miles remaining, and the average speed necessary for the remainder of the trip for each family member to win. Eight short term games surround the central challenge, designed such that multiple family members can play at the same time. These include logic games, code generation and breaking games, word problems and puzzles, road sign games focusing on shape, estimation games (e.g., how many silver cars you will see in three minutes), prime number bingo, and number pattern games using license plate values.

A point system links the central estimation game to the shorter term games, such that the central game is worth the majority of points, but it is possible to win even without the central game by playing a large number of the short term games.

Figure 6: Go Road Trip Records Section

At the end of the trip, a record is generated that the family can access on the mobile device or on the web. This includes information about the trip destination, the departure and arrival times, the family member who had the most accurate guess about arrival time, and the family member with the most points overall. Future developments will allow the inclusion of photographs taken with the mobile device during the trip to be linked to the *Go Road Trip* record.

User Studies:
Seven families with middle school students will field test the *Go Road Trip* application while traveling by car over the winter holidays. The application will automatically log each family member's actions within *Go Road Trip*. In addition, we will audio record the family's interactions in the car in order to understand the conversation and social negotiations that occur around the application and the particular challenges. Analysis will focus on whether *Go Road Trip* supports and encourages mathematical talk among family members, and how the mobile device mediates the family's mathematical interactions, and whether the application needs to accommodate play from multiple devices.

Discussion and Summary

The first value of the RR&D process is that it helped our team to understand the conditions and features of the learning environments under development. The mobile math environments had the potential to be extremely complex, and being able to rely and double-check design and development decisions against the knowledge base developed from the basic and user tests was extremely helpful in our ideation phase. It helped us delineate our development space and evaluate the many "learning environment interface issues." Second, exercising our design and development team through research, technological development, and user testing concerns had huge influence on each mobile environment. It enabled us to do design and development work that was research based and real-world tested, and we found this to be important in understanding how mobile platforms can best be developed as learning applications. The RR&D process caused us to have rigor in our process and also take chances that would please our users. It allowed us to work in the third space between the hypothetical and the practical. Third, because our work is being done in a university setting, the nature of the work we engaged created links between the theories of learning research we are involved in and the real-world mobile environments we hope to contribute and bring into the lives of families. This is not an accidental arrangement; it is in the spirit of a rigorous and reciprocal approach to research-based design.

We recognize that a lengthy and complex basic research phase is not a realistic goal for some development processes, although we contend that the value of timely, on-topic, and relevant research should not be denied by developers. The value of developing designs and development goals based on research has been proven to us on our own work. We are quite aware that changes in mobile platforms and capabilities drive development teams to a fast-paced development schedule, where even user-tests can seem like a luxury. We believe that it is possible to use research results from relevant studies in a field in a reciprocal fashion in order to ground mobile development—in our particular circumstances, where there is an agenda for learning to be supported with mobile technology. The reciprocal research and design process has helped us ideate our designs, generated our design criteria, and helped us deal with trade-offs in a confident way.

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