Technology for Promoting Scientific Practice and Personal Meaning in Life-Relevant Learning

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ABSTRACT
Children often report that school science is boring and abstract. For this reason, we have developed **Life-relevant Learning (LRL) environments** to help learners understand the relevance that scientific thinking, processes, and experimentation can have in their everyday lives. In this paper, we detail findings that aim to increase our understanding of the ways in which technology can support learners' scientific practice and their personal meaning in LRL through the integration of two mobile apps into an LRL environment. Our analysis of the artifacts created in these systems show that technology must strike a balance between structured scaffolds and flexible personal design to support learners' scientifically meaningful experiences. Our data suggests that integration of media forms and mobile technology can provide creative ways for learners to express their scientific thinking, make artifacts of their personally meaningful experiences, and individualize artifacts in scientifically meaningful ways.

Categories and Subject Descriptors
K.3.1 **[Computer Uses in Education]**: Computer assisted Instruction (CAI)
H.5.2 **[Information Interfaces and Presentation]**: User Interfaces – User-centered design

General Terms
Design, Human Factors.

Keywords
Life-relevant learning, scientific inquiry. mobile computing, children and technology

1. INTRODUCTION
Learners frequently report that science in formal education environments can seem abstract, and therefore "boring" and irrelevant to their everyday lives [2, 34]. Instructors and curricula often present school science in a controlled and pre-determined fashion. For example, recipe-like experiments fail to convey the actual messiness, uncertainty, and risk-taking found in authentic science [13]. In such cases, learners not only get an inaccurate epistemological view of what science is really about, they also sense a lack of agency in practicing and learning science for their own benefit. Young learners need to feel that science is not only relevant, they also need to see that their participation in scientific experimentation and argumentation *matters* [11].

Based on these issues in science learning, we have developed **Life-relevant Learning (LRL) environments** to help learners understand the relevance that scientific thinking, processes, and experimentation can have in *their* lives. LRL environments are programs in which youth come together to participate in Science, Technology, Engineering, and Math (STEM) fields in the context of their own interests and goals. LRL environments are designed to help learners develop scientific thinking skills (e.g., ability to ask questions, design experiments, collect evidence, make objective observations, develop claims) in ways that are accessible and meaningful to them [8, 12, 14]. Our work designing LRL environments involves: (1) developing learning activities in physical environments that are interesting to learners and relevant to their lives and (2) building technology that supports learners' scientific practice in everyday contexts. Our aim in these environments is to encourage and promote *scientifically meaningful experiences* – or experiences that involve both scientific practice and personal meaning for learners.

Because we aim to support science learning in children's everyday lives, we must draw upon the tools and resources with which children are already familiar. LRL designs must consider the role of technology and how it supports science learning in everyday contexts. A wide variety of technology is already available to learners in their home and school environments. Social media (e.g., YouTube™, SchoolTube™, Facebook™) and mobile devices are all around them [1, 9, 27, 28], yet learners are rarely invited to bring these resources into their learning experiences, except in very controlled ways [24]. We need to better understand the process and effects of incorporating the technologies that are already personally meaningful in learners' daily lives into learners' experiences in science.

Our goal is to understand how technology can be designed to strike the desired balance between the scaffolding needed to support learners' scientific inquiry, and the flexibility needed to explore their own interests and modes of personal expression. Our approach has been to use technologies that are readily available in learners' home and family environments (i.e., mobile devices,

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cameras, audio recorders) in an out-of-school education setting. In this paper, we present an analysis of how these technologies promoted and inhibited learners' scientifically meaningful experiences. We use this analysis to then inform the design of future technology for supporting LRL.

The context of our analysis is our LRL environment, *Kitchen Chemistry*. Kitchen Chemistry (KC) is designed to help upper elementary and middle school learners (ages 9-14) use science to make and perfect dishes and to investigate the underlying causal factors in cooking phenomena. We aim to understand how the scaffolding for scientific inquiry and the support for telling personally meaningful stories in two mobile software systems, *Zydeco* and *StoryKit*, influence learners' scientifically meaningful experiences. Specifically, we ask: How did Zydeco and StoryKit support and inhibit learners' scientific practice and their personal meaning? We ask this question in order to understand how future support systems for LRL can be better designed to support learners' scientifically meaningful experiences.

2. BACKGROUND

2.1 Supporting Scientific Practice

Aspects of scientific practice that youth can best learn through cooking activities include the design of investigations, interpretation of data, and use of data as evidence [15]. Such practice includes, but is not limited to, generating research questions, designing experiments to answer questions, making observations, taking measurements, and studying others' research [14, 37]. While these actions may be encouraged in science classrooms, they are often enacted in experimentation that is simple and fixed [14].

In contrast, *authentic scientific practice* involves doing science (1) in the context of real-world problems, (2) where the full range of variables can be tested and the full range of outcomes may be unknown, and (3) where procedures for answering questions are chosen at least partially by participants [14, 23]. In addition to the complexities of engaging in authentic scientific practice, learners need help pursuing their interests and goals scientifically [17]. Furthermore, cooking activities are physically demanding. In the midst of busy, messy, and exciting projects, learners need help focusing on the relevant scientific aspects of their experiences [22].

In previous work, we learned how to promote scientifically meaningful experiences in LRL environments [15]. We used text-based software on laptops to support learners' goal setting, planning, and imagination. The technology supporting the environment played an essential role in providing an organized repository of the community's experiences and placed this information at learners' and facilitators' fingertips. However, facilitators played a large role in driving the software use. They often had to prompt learners to write stories and short explanations from their experiences. They also needed to ask learners specific questions about their experiences and type learners' dictation in order to create stories [16].

While this was effective for supporting learners' scientifically meaningful experiences, technology should help to distribute the cognitive responsibility between all the participants in the environment [44]. We need to develop technology that learners can and want to use on their own. While our technology was previously designed to support LRL scientific practice, it was less focused on supporting learners' personal meaning during their experiences. Therefore, learners were less likely to use it on their own during the LRL program and they did not use it outside of the program, even when they extended their experiences from the program to their home life.

2.2 Technology for Promoting Personal Meaning In Science

One approach for engaging learners in scientific inquiry with technology in personally meaningful ways is to allow them to carry the technology into their own worlds. By exploiting the portability and location awareness of mobile applications, learners gain opportunities to capture science-based experiences in places – and at times – that are interesting and immediate to their interests. Another approach for using technology to engage learners in more personally meaningful scientific experiences is through storytelling. By using common (i.e., intuitive) storybook formats, digital storytelling technologies give learners freedom to personalize their early forays into scientific inquiry in ways that are meaningful to them.

2.2.1 Mobile Technologies Promoting Personal Meaning in Science

Mobile technology designs enable learners to collect and analyze data in the world around them. Furthermore, researchers and educators can move with the learners to capture and analyze data through a variety of contexts, both in school and out-of-school. Mobile technologies can also provide location-aware and location-dependent visualizations to support their science learning, and enable learners to capture their scientific experiences [40, 41, 45]. For example, Wyeth and MacColl's [44] *Noising Around* system enabled learners to use mobile devices for measuring and analyzing sound levels around their schools, and Roger and Price's [40] *Ambient Wood* system enabled learners to explore woodlands with mobile technology. However, much of this technology has been designed in highly structured ways, giving learners little flexibility for exploring answers to their own questions or collecting data relevant to their own curiosity [45].

Moving beyond the context of school, researchers have been designing technology for supporting learners' *nomadic* scientific experiences, or experiences that happen in multiple settings. For example, various museum researchers have been designing technology to support learners as they move around in museums, helping them to capture their experiences for later reflection in the classroom, thus extending the experience [20, 26]. Mobile devices play an important role in helping learners capture their experiences at the exhibits they visit. These museum exhibit captures can then be sent to web pages that visitors can return to later to get more information about, or to reflect on the exhibits.

While mobile applications, such as Zydeco, have been effective for supporting and extending learning experiences at science museums [10, 31], technology that specifically supports personally meaningful scientific inquiry is scarce. A deeper understanding is needed of how technology-based scaffolds such as Zydeco can fit in LRL contexts where scientific inquiry occurs in physically demanding activities (e.g., cooking, sports).

2.2.2 Storytelling Technologies for Promoting Personal Meaning in Science

Another way in which researchers have attempted to motivate learners in science education is through the use of storytelling [4, 5, 25, 35, 38, 42]. Through stories, educators, researchers and students themselves can be motivated to "draw the content of the lesson into [their] life-worlds" [35]. Many narrative approaches in

science education have emphasized the history and story behind particular scientific personas, such as Galileo [36], or the context of particular scientific discoveries [38]. Our focus is on narrative approaches that ask learners to capture their personal experiences in science [e.g., 3, 4]. By drawing upon their everyday experiences and personal narrative-based patterns of discourse, learners can engage more deeply with science, and more easily appropriate increasingly complex patterns of scientific discourse [4, 5, 42].

Authentic scientific inquiry is a process of scientific storytelling that involves conjecturing, experimenting, and iteratively building explanations [5, 25, 42]. Many scientists see inquiry as a process of connecting what is known with what is possible; in other words linking fact and fancy, as stories often do [3, 29, 42]. Learners are not often exposed to the iterative and mutable nature of scientific inquiry [33], yet this is the very element that often excites experienced scientists [42]. Storytelling offers learners a familiar, intuitive expository structure with which learners can experience science as a personal process of discovery, and thus engage more deeply in it [4, 25, 42].

Technologies that support narrative-based expression range from generic presentation-like applications (e.g., PowerPoint^{TM}) to more complex digital storytelling tools that include video capture, music integration, and editing [43]. Storytelling technologies typically offer more flexible means of expression (e.g., images, picture-book metaphors) than existing mobile data collection tools and capture entries that reflect personal experiences [6, 43]. We draw upon one such system, StoryKit, in Kitchen Chemistry, to help learners capture their scientifically meaningful experiences.

2.3 Technology for promoting scientifically meaningful experiences in Kitchen Chemistry

To support learners' scientifically meaningful experiences, we have incorporated Zydeco and StoryKit into Kitchen Chemistry. While Zydeco promotes the types of scaffolding learners need for scientific inquiry, StoryKit provides tools that enable creative expression for supporting learners' personal meaning.

Zydeco [10] (**Figure 1**) is an iOS app designed to support scientific inquiry across school and museum settings (and other informal environments). We thought Zydeco would work well in LRL environments because it was designed to provide scaffolding for scientific practice, while also giving learners choice and control during their scientific experiences. With Zydeco, learners can choose what type of data they collect during their experiences. Zydeco then provides scaffolds and prompts for capturing that data. Specifically, Zydeco supports learners in the following scientific activities:

- Developing scientific questions before informal experiences;
- Capturing evidence to develop claims to answer those questions during informal experiences; and
- Making claims supported by evidence after their experiences.

For each artifact learners capture, Zydeco prompts them to record what is important about that data and to tag the data with scientific observations (**Figure 1**). Later, the system provides support for guiding learners to make claims regarding their investigations using their data as evidence.

While Zydeco provides the structure needed for supporting learners' scientific practice, StoryKit, a digital storytelling iOS app, offers more flexibility and freedom for learners to explore their scientific interests. StoryKit was designed in the University of Maryland's Human-Computer Interaction Lab (HCIL) by an intergenerational design team of children and older adults to enable children to write stories that they could share with distant relatives. Because StoryKit is a publicly available iOS app, many educators and families have used it to help children reflect on their experiences, whether in formal or informal settings [6]. We have found that StoryKit's simple, but well-integrated multimedia design enables learners of all levels, from early readers and writers through early undergraduate students, to create personally expressive stories across a wide variety of topics [6, 7].

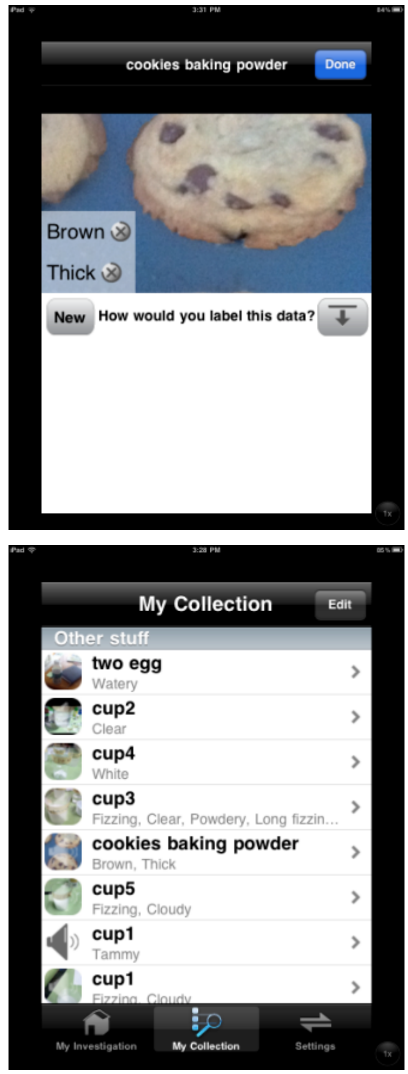

Figure 1: Zydeco prompts learners to create tags of photo, video, or audio data that they capture (top). Once learners have captured their data, titled it, created an audio clip for it's importance, and tagged it, the entry is added to their library of data for a particular investigation (bottom).

Learners can use StoryKit to create electronic storybooks by typing in text, recording sounds, taking pictures, and/or drawing on the device's touch screen. They can then share their creations by uploading them to a server. StoryKit's portability, context sensitivity, support for individuality, and social interactivity [7] enable learners to make personally meaningful artifacts and form bonds with others as they create stories collaboratively. These

Table 1: Comparison of Media Affordances between Zydeco and StoryKit

	ZYDECO	STORYKIT	NOTES
PHOTOS/ IMAGES	✔	✔	**StoryKit**: Allows multiple images (as many as desired by user). Images can be imported from photo gallery. **Zydeco:** Allows one image per data entry.
AUDIO	✔	✔	**StoryKit**: Each audio clip is limited to 1 minute. Allows multiple audio clips per page. **Zydeco**: Each audio clip is limited to 30 seconds. Allows one audio clip per data entry.
TEXT (narrative)	✖	✔	**StoryKit:** Narrative-based, free-form text. Allows multiple, scrollable text boxes per page. **Zydeco:** Title descriptions of entries. Allows one per data entry.
TAGS	✔	✖	**Zydeco**: Tags are Zydeco's equivalent of "text." Typically one-two word phrases that reflect observations about data the learners have collected. Students can generate tags in advance and tap-to-apply them when collecting data or create new tags.
VIDEO	✔	✖	**Zydeco**: Allows one video per data entry.
PAINT	✖	✔	**StoryKit:** Allows students to draw on a story segment, potentially on top of text or images.

same characteristics make it a nice fit for learning in and out of the classroom. We have anecdotal evidence that science teachers are using StoryKit to motivate students (personal communications, April – October 2011). However, we have not previously used StoryKit to support learners' scientific inquiry.

Both StoryKit and Zydeco enable learners to capture data during their experiences in the physical environment. This promotes reflection during their activities and after the investigations. They also support the capturing of data in multiple formats (e.g., photographs, audio recordings, text) found to be appealing to young learners. We use the two tools together because we thought the combination could provide the balance needed to support both scientific practice (emphasized in Zydeco's scaffolds) and personal meaning (emphasized in StoryKit's creative expression tools). **Table 1** shows a comparison snapshot of the various media each tool can capture.

3. DESIGN OF THE LEARNING ENVIRONMENT

3.1 Design of Kitchen Chemistry

Kitchen Chemistry is an after-school or summer camp program where learners engage in scientific practices through cooking activities. Holding the program outside of school enables learners to choose the directions of their scientific inquiry without being bound to a particular curriculum. To provide an environment in which learners can participate in scientific practices to design investigations that are personally meaningful to them, we developed two activity sequences.

First, learners engage in ***semi-structured activities*** that help familiarize them with cooking and science practices. In these activities, learners engage in cooking experiments where they vary the amounts of the ingredients in a recipe. They then examine the results to answer a scientific question, such as observing what eggs do in brownies. The semi-structured activities also include non-cooking experiments in which the ingredient variations in their cooking experiments are highlighted specifically to help learners think about the underlying scientific phenomena. Learners participate in these semi-structured activities to prepare them for flexible exploratory activities called ***Choice Days.*** During Choice Days, learners are given the opportunity to use what they have learned to iteratively perfect a recipe of their choice using scientific investigation.

3.2 Technology in Kitchen Chemistry

In Kitchen Chemistry, learners use the StoryKit and Zydeco ***mobile technologies*** (on iPads™) to conduct their investigations and reflect on their observations. We use both StoryKit and Zydeco to support learners' scientific practice and to help them reflect during and after the investigations on the scientific aspects of the activities.

Learners used Zydeco on Day 1 of the program to compare and contrast different characteristics of store-bought cakes, cookies, and breads. During this investigation, we aimed to help them think about what roles leaveners play in those foods. Learners used StoryKit on Day 2 for a semi-structured activity in which they made brownies with different amounts of eggs and examined how eggs emulsify oil and water in a non-cooking experiment. They then used Zydeco again on Day 3 of the program for their semi-structured experiment in which they made cookies with different leaveners (and again engaged in a non-cooking experiment).

We used the *cooperative inquiry* technique of sticky-noting [19] at the end of both semi-structured activities on Day 2 and Day 3 so that learners could tell us what they liked and disliked about each technology and give us design ideas for the corresponding technology. During Choice Day activities, learners could also choose whether they wanted to use StoryKit or Zydeco.

4. METHODS

Our research focus for this paper was to understand how the StoryKit and Zydeco software systems promoted learners' scientific practice and personal meaning. We address this question in the context of an all day, one-week summer camp implementation of the Kitchen Chemistry program held at a local private school. A total of nine learners (ages 9-13) participated in the program, six of whom participated consistently each day. The participants were from different public and private schools in the Maryland area. Researchers (including four of the authors of this paper) served as facilitators in the environment.

As a part of a larger study on LRL using Kitchen Chemistry, we collected video recordings of all semi-structured activities and whole group discussions. Facilitators also recorded post-observation field notes that described what we thought were the most significant aspects of the day. We collected learners' entries in the Zydeco and StoryKit software systems, and paper-based artifacts from their cooperative inquiry activities. In addition, four learners agreed to be interviewed, allowing us to understand their experiences in the activities and the role of technology from their own perspectives.

To focus on the ways in which learners used Zydeco and StoryKit, their StoryKit stories and Zydeco entries constituted our primary data source. We also used the learners' feedback from the sticky notes' sessions and field notes for triangulation. In our analysis, we aimed to understand:

- How does learners' use of the technology reflect their scientific practice?
- How does learners' use of the technology reflect their personal meaning?

Our goals were to understand how the two systems supported or inhibited learners' scientifically meaningful experiences and to draw out design guidelines for supporting such experiences.

We used a grounded theory approach [18] for the content analysis. Individually, two of the authors applied open coding on a sample (~25%) of the total StoryKit and Zydeco entries collected. In a collaborative axial coding session, the two authors compared and contrasted our open code set to identify scientifically meaningful ways in which learners were using the technology and aspects of the technology that promoted that use [15, 16]. This coding session also included comparative review with existing frameworks for scientific inquiry practices [13, 37], to identify points at which the Zydeco and StoryKit entries showed the learners engaging in authentic scientific practices. We followed a constant comparative approach during axial coding, by:

- Examining common themes and making comparisons within individual entries (e.g., a single StoryKit story or Zydeco entry);
- Comparing/contrasting codes across a set of entries from each technology (e.g., a set of Zydeco entries); and
- Comparing codes across both technologies (e.g., a set of Zydeco entries and a set of StoryKit stories).

Three authors used the resultant coding scheme to analyze the complete Zydeco and StoryKit corpus. For example, codes reflecting scientific practice included "showing measurement procedures" and "making scientific observations". Examples of codes reflecting personal meaning included "playfulness" (e.g., a photo of learners making faces when tasting vinegar), or "documenting the group experience". **Section 5** provides details on the coding scheme. Each of the three authors coded a third of the corpus.

We continued to refine our coding frame during the next round of coding. For example, we added the theme *documenting the experiment* to reflect the observed scientific practice of describing the contextual details of their experiments. Inter-rater reliability for the qualitative data was based on iterative, constant comparative member checks among the coders [18], versus being quantitatively computed. To confirm the strength of our coding frame, we selected a representative cross-section of the entire corpus that all three coders checked simultaneously for coding agreement. There was near-unanimous agreement on the final coding scheme that led to our findings.

Specifically, we identified three sets of themes with regard to our analysis questions. The first set dealt with how learners used the integrated media (e.g., "interview style"). The second set of themes addressed the common types of scientific contributions learners and facilitators made with the technology (e.g., "making scientific observations"). The final set of themes addressed the personally meaningful ways in which we saw learners use the technology (e.g., "documenting the group experience"). Overall, our coding results shed light on the main questions we posed for this paper: What aspects of technology seem to "support scientific practice" and what aspects "support personal expression?"

5. FINDINGS

In this section, we will first address our analysis questions regarding learners' use of StoryKit and Zydeco in Kitchen Chemistry. We will then use that analysis to understand how Zydeco and StoryKit each provided supports needed for scientifically meaningful experiences.

5.1 General Use of StoryKit and Zydeco

We found that tags were the media form learners used the most in Zydeco (382 tags were created) and that photos were the media form they used most in StoryKit (303 photos were taken). While the total number of entries in Zydeco (n=153) was close to the number of pages in StoryKit (n=188), we found that when given a choice of which technology to use, learners unanimously chose to use StoryKit. However, because they used Zydeco for an introductory investigation, as well as for a semi-structured investigation, they used each technology for two Kitchen Chemistry sessions.

5.2 How Technology Supported Learners' Scientifically Meaningful Experiences

Scientific Practice. In support of learners' scientific practice, we assert that five themes are present with regard to how learners and facilitators used the technology. Specifically, learners used the technology to:

- <u>Raise questions</u> (albeit, sometimes playfully) that exhibited their curiosity about ingredients, procedures, and reactions they were experiencing;
- <u>Make scientific observations</u> that were objective, and either descriptive or quantitative;
- <u>Compare</u> experiment variations;
- Show and describe their <u>measurement procedures</u>, capturing their processes for measuring accurately; and
- <u>Document their experiments</u> by providing contextual details about the experiment (e.g., procedures they were carrying out, how much of an ingredient they were using, why they were using a particular procedure).

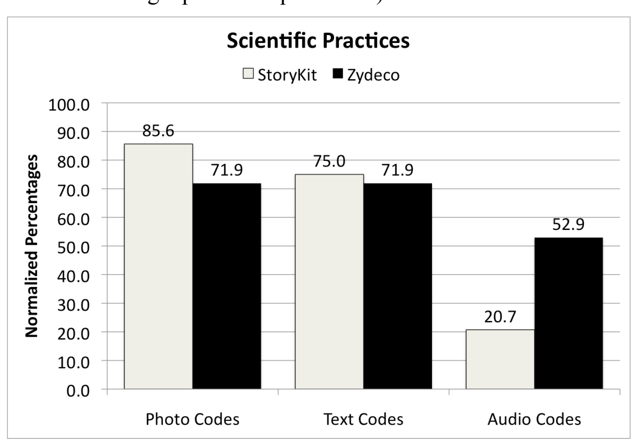

Figure 2: Scientific Practice themes noted across media types in StoryKit and Zydeco.

Figure 2 displays a frequency analysis of the normalized coding counts for the scientific practice themes noted across media tools supported in both StoryKit and Zydeco (photo, audio, and text). Note that a single entry could have been coded as multiple forms of scientific inquiry (e.g., comparing experiment variations and showing measurement procedures). In this case, that entry would be counted in the scientific practice more than once. Consequently, the graph not only represents the quantity of scientific codes, but also includes the strength of those codes.

Photos, text (in the form of text boxes in StoryKit and title prompts in Zydeco), tags (in Zydeco), and audio (mostly in Zydeco) were the most used media forms for learners' display of their *scientific practice*. With the use of photographs, learners could capture visual descriptions of their dishes and experiments at various stages of preparation (e.g., before and after baking). They would also use text and audio to describe their experiment results. Participants often used photos in both technologies to capture their procedures for accurate measurement. Learners also used the drawing tool in StoryKit to draw on a ruler or measurement device (**Figure 3**), thereby demonstrating their measurement procedures to others for accuracy and verification (e.g., measuring the height of the brownie batter by dipping a knife into it and then measuring how high the batter came up to on the knife). Facilitators often guided learners' measurement procedures and helped them to capture artifacts of their measurement procedures.

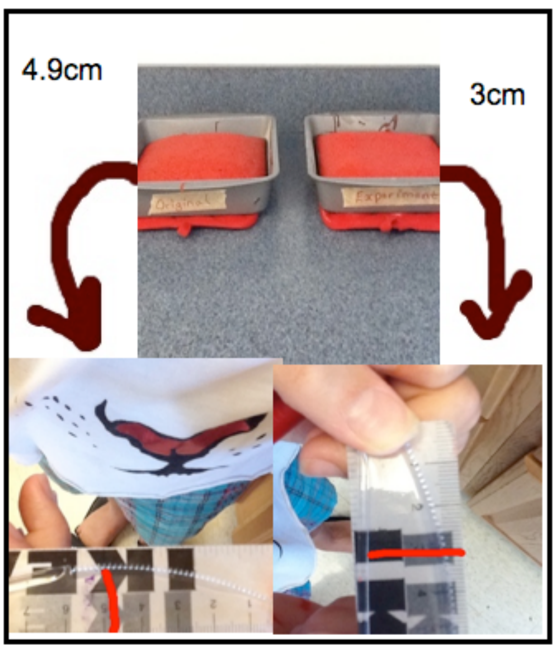

Figure 3: Learners use drawing, photos, and text in StoryKit to display measurement procedures, make quantitative observations, and compare variations in experiment results.

Personal Meaning. We found that learners used the technology to document their personally meaningful experiences in Kitchen Chemistry and they used the technology itself in personally meaningful ways. Specifically, we found learners used the technology to:

- Document their group experience by using the technology to record personal aspects their cooking experiences;
- Make creative artifacts of their experiences, such as using novel descriptive phrases for chemical reactions ("king quick big fizz" to describe the fastest acid-base reaction learners observed), or creating color-matching, artfully drawn borders for pages in their StoryKit stories; and
- Make playful artifacts, such as hand drawn pictures.

Figure 4 displays a frequency analysis of normalized coding counts for *personally meaningful* themes noted across media features supported in both StoryKit and Zydeco. Note that a single entry could have been coded as multiple forms of personal meaning, in which case, that entry would be counted in personal meaning more than once. For example, a photo could document the group's experience of concocting a new recipe and could be playful as well (e.g., learners mugging for the camera with their final product). This means that the graph not only represents the quantity of codes, it also includes the strength of those codes.

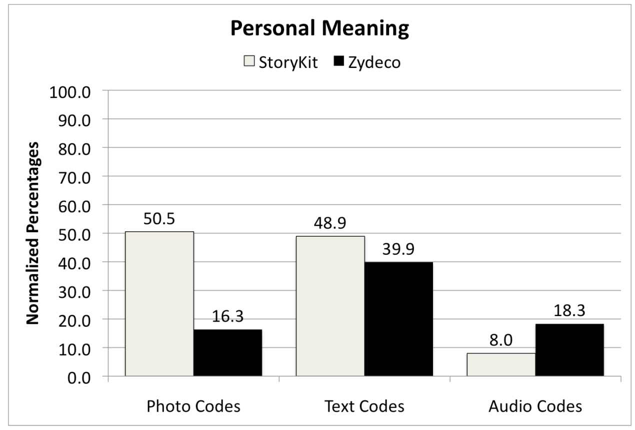

Figure 4: Frequency of media used in personally meaningful ways across Zydeco and StoryKit.

Figure 5: Learners used StoryKit to draw colorful backgrounds for their stories. This example also reflects the Measurement Procedures and Scientific Observation themes.

We observed that text (in the form of text boxes in StoryKit and title prompts in Zydeco), photos, and drawing were the primary tools used for displaying learners' personal meaning. In StoryKit, they used text, color, drawings, and photos in creative ways to express themselves. For example, learners used the drawing tool

to create colorful backgrounds for their story pages (**Figure 5**). Learners often used the software in playful ways, taking pictures of themselves making playful faces, using text in playful ways (e.g., making smiley faces, funny sayings, exclamation marks), using drawings to support their play, and using audio to record funny sayings or sounds. Sometimes these artifacts were just playful and sometimes they were incorporated into a scientific artifact. Learners also used photos, text, and drawing to document the roles they took on, how they felt about the processes and the final results of their experiments (e.g., **Figure 6**). Note that permissions were received from all parents for the children in the study to participate and share images of themselves (as they wished) for research or publication purposes. Therefore, we have not blurred facial images of the children.

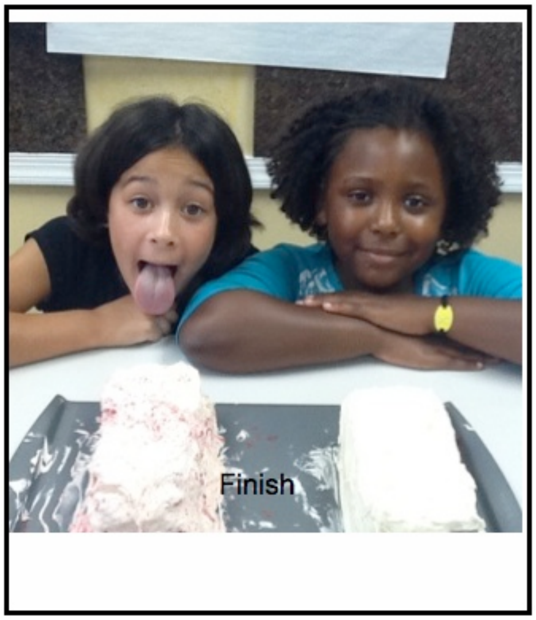

Figure 6: Learners use StoryKit to document their finished product, marking their cooking accomplishment of making two red velvet cake variations. This is an example of the Documenting the Group Experience theme.

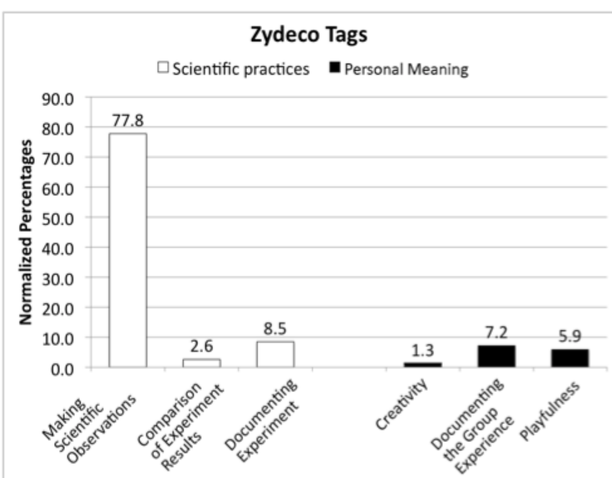

Figure 7: Tag Use in Zydeco (reflecting *both* scientific practice and personal meaning themes).

Figure 7 shows the frequency analysis of coding counts for tags in Zydeco. Tags are a feature unique to Zydeco; they are not available in StoryKit. Only the top three scientific practice codes are displayed (white bars on left). The top three codes reflecting personal meaning are also shown (black bars on right). Learners used Zydeco tags most often when making scientific observations.

Figure 8 summarizes the frequency analysis of coding counts for drawing in StoryKit. Drawing/painting is a feature unique to StoryKit; it is not available in Zydeco. Only the top three codes reflecting personal meaning are shown (black bars on right). The top three scientific practice codes are also displayed (white bars on left). Learners can use the draw/paint tool in their StoryKit stories most often to craft creative backdrops for photos. They also used drawing to point out items of interest in images (e.g., measurements, comparisons of results).

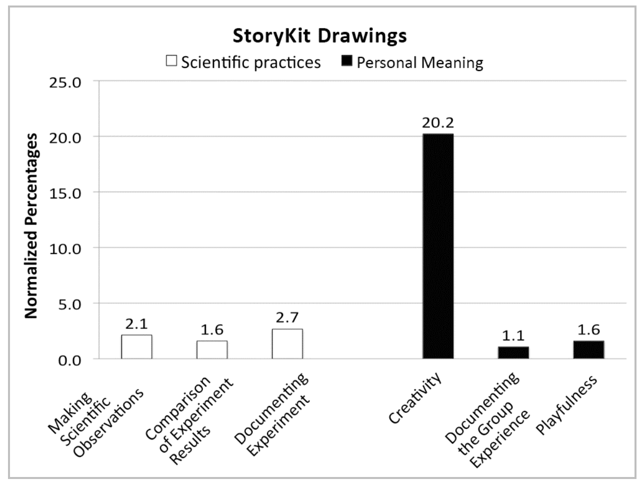

Figure 8: Drawing Use in StoryKit (reflecting *both* scientific practice and personal meaning themes).

5.3 Media Forms for Supporting Scientifically Meaningful Experiences

We found that photos, text, and audio were used to support a range of scientific practices and personally meaningful uses. Video, while not used as frequently, also supported both scientific practice and learners' personal meaning. We suspect that learners may not have used video as much because of difficulties they encountered with viewing their videos in the Zydeco library after they were taken. However, support for videos is a feature learners requested in our StoryKit design sessions. Tags, on the other hand, were primarily used for supporting scientific practice. Likewise, drawing was primarily used for supporting learners' personal meaning and individualization.

5.4 Support for Scientifically Meaningful Experiences in StoryKit and Zydeco

Zydeco's structured supports for scientific practice both afforded and constrained learners' scientifically meaningful experiences in Kitchen Chemistry. Zydeco's structured supports helped learners to think scientifically and to produce scientific artifacts from their experiences. The system prompted learners to think scientifically about the artifacts they were creating with a prompt in each data entry that asked learners to record audio stating, "What's important about this?" This prompt encouraged learners to think about the scientific relevance of their data.

Even when learners were unsure about how to answer this question, they used Zydeco as an "interview style" question to get other group members involved in the data capture. On other

occasions, Zydeco's audio prompt for each entry supported the capturing of learners' and facilitators' candid discussions, often capturing the scientific roles learners were taking on and the scientific connections they were making during their activities. In addition, tagging their data prompted learners to record descriptive and quantitative observations of their data. Tags could then be used later to group data collected across groups in support of helping learners make claims grounded in evidence.

Although Zydeco supported learners' scientific practice quite well, its tighter control of creation of artifacts limited learners' ability to integrate media forms and may have added difficulty in creating artifacts during the busy activity of cooking. In Zydeco, learners had to go through a specified sequence of steps in order to create an entry. The different forms of media used in one entry (e.g., photos or video, audio, and textual tags) were then presented to learners in a consistent presentation determined by Zydeco. Therefore, we did not observe as much creativity and playfulness in learners' and facilitators' use of Zydeco. Moreover, learners did not use Zydeco to document as many of their personal group and individual experiences in Kitchen Chemistry.

While these constraints may not seem particularly compelling to many science educators, they did impact learners' perspectives and later use of Zydeco. When given a choice of technology on Choice Day, learners' unanimously chose to use StoryKit over Zydeco. In the Zydeco design session, the most common theme in learners' comments was that they wanted more StoryKit-like features (e.g., <u>Dislike</u>: You can't put it together like a book; <u>Idea</u>: I want to write stories with Zydeco). Effectively, the power of flexible and personal expressiveness afforded by StoryKit was a means for personal engagement in science.

StoryKit, on the other hand, enabled learners to create sequential and free-form stories. Free-form integration of media supported learners' ability to make personally meaningful artifacts. In StoryKit design sessions, learners' comments reflected their enjoyment of these capabilities in StoryKit (e.g., <u>Like:</u> That we can make cool designs; <u>Like</u>: Coloring part cool designs; <u>Like</u>: Makes writing fun). This is consistent with Wyeth and MacColl's [39] findings. When the researchers looked at free-form paper-based supplements given to children, along with their more structured technology, they too found that children wanted to personalize their artifacts. StoryKit's integration of media forms supported that personalization with ease and simplicity needed for creation during physically demanding activities like cooking.

Telling stories provided a motivating context for learners to think scientifically. However, there was no mechanism for helping learners to look at data collected across groups. In addition, learners needed ways of grouping data collected in their stories so that they could make sense of the data and draw conclusions. While learners often used the drawing tool in StoryKit to make quantitative observations, our findings suggest it may be important to provide easier means to enter quantitative data in ways that facilitate later computation and even connection of those computations to learners' personal experiences (e.g., the flattest cookie was 1cm and tasted the yummiest).

6. DISCUSSION

Our analysis largely points to the need for balancing structure and freedom to promote scientifically meaningful experiences. Learners needed structure for promoting their scientific practice and flexibility for promoting their personal meaning. Our findings point to ways in which we can begin to provide this balance between structure and freedom with technology for LRL.

6.1 Balancing Structure: Lessons Learned from Zydeco

While Zydeco allowed learners to freely choose what data they would annotate, it tightly scaffolded learners' creation of data artifacts. That scaffolding helped learners to create more scientific data entries. However, learners unanimously chose not to use it when given a choice. There was one form of scaffolding, however, that learners used heavily, were able to create with ease, and wanted to use more of – tagging. We found that tagging was an easy way to prompt learners to think scientifically about the artifacts they were collecting. While creating tags was heavily prompted in the software system (i.e., it was difficult for learners to create an entry with no tags), **learners could create them easily and quickly**. Learners thus typically created several tags per entry (an average of 2.5 tags per entry). We suspect that tags were also used so prominently because of the software's **prompting to create them at opportune times** – at the point of artifact creation.

6.2 Balancing Structure: Lessons Learned from Facilitator Support

Another important aspect of the scaffolding in Kitchen Chemistry (and in LRL programs more generally) is facilitator support. Facilitators play an important role in helping learners begin to ask questions, design experiments, collect data, and make claims [15, 46]. In Kitchen Chemistry, facilitators worked with each group, prompting them to engage in such scientific practices, modeling inquiry practices themselves, and helping learners develop inquiry skills. Facilitators also needed to help learners make scientifically relevant choices and connect learners' goals to scientific practice [46]. In the process, the technology supported both the learners engaging in scientific practice and the facilitators in scaffolding learners' inquiry. Using the technology to create artifacts from their scientifically meaningful experiences then helped to combine the voices of the learners and facilitators [16]. The use of free-form integrated media, and storytelling then helped learners and facilitators to combine their voices in new, more radiant, creative, playful, and scientific ways.

6.3 Balancing Freedom: Lessons Learned from StoryKit

StoryKit provided learners freedom by allowing them to integrate media forms (i.e., audio, text, photos, and drawings) in their own unique ways. Freely being able to choose what media form to use allowed learners to quickly capture and annotate their StoryKit entries. Supporting multiple media forms also enabled learners to use those media forms that were easiest, most natural, and personally meaningful for them. We have found this to be of great importance for motivating learners to document and reflect on their experiences [20]. This **ease of creation** along with learners' **freedom to individualize** the artifacts they created helped learners to use the tools in scientific and personally meaningful ways.

However, there was one form of structure that StoryKit did impose on learners – the goal of telling a story. We found that **stories provide a particularly motivating and natural context for supporting learners' scientifically meaningful experiences**. The components of stories (i.e., intro, body, climax, conclusion) line up nicely with scientific inquiry processes (i.e., asking a

question, designing an experiment, collecting data, making claims to explain data). Often technology is used to make work happen faster. Here, we argue that the technology as a storytelling tool slows the activity down to allow for reflection in situ.

7. CONCLUSION

This study looked at the usage of two systems in the context of supporting scientifically meaningful experiences. StoryKit had not previously been used for scientific practice, but its support for sequential storytelling worked well for scaffolding learners' science inquiry. Zydeco was developed to support scientific practice across classrooms and informal learning settings like museums. To support scientific inquiry across such contexts, researchers had previously found a need to balance structure and flexibility in Zydeco's design [10]. However, to promote and enhance learners' personal meaning in scientific inquiry experiences, the supports and features needed to balance structure and flexibility should be modified.

Some emerging design recommendations for other researchers seeking to support learners' scientifically meaningful experiences are:

- Drawing tools help promote learners' personal expression;
- Tags enable scientific reflection and support later data organization and visualization of data collected across groups; and
- Structured supports such as tagging should be available at opportune times, but streamlined when not needed

The ability to draw, paint, or sketch within a mobile storytelling application has been a consistent feature requested by children during design and evaluation sessions of StoryKit and related storytelling prototypes [21, 39]. Drawing often serves as a free-form tool that learners can use to personalize their artifacts.

Previous research on Zydeco had analyzed students tag use and found it promoted learners' reflection on the data they were collecting, and enabled review and usage of the data later [30, 32]. Tagging was found to be useful in this study, though there were times when the process of tagging data interfered with the activity. Sometimes students needed to quickly collect data, or were unsure how to label it at the time and needed to come back to it later; in these cases, it would be useful to have a more streamlined approach to data collection.

Our findings in this paper show that technology can support learners' scientifically meaningful experiences. Our data suggests that integrated use of multimedia and mobile technology can provide creative ways for learners to express their scientific practice, make artifacts of their personally meaningful experiences, and craft artifacts in scientifically meaningful ways.

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9. REFERENCES

[1] Ahn, J. 2011. Digital divides and social network sites: which students participate in social media. *Journal of Educational Computing Research*, 45, 2, 147-163.

[2] Atwater, M. M. 1996. Social constructivism: infusion into the multicultural science education research agenda. *Journal of Research in Science Teaching*, 33, 8, 821-837.

[3] Bakhtin, M. M. 2008. *The Dialogic Imagination: Four Essays*. (M. Holquist, Ed.). Austin: University of Texas Press.

[4] Ballenger, C. 1997. Social identities, moral narratives, scientific argumentation: science talk in a bilingual classroom. *Language and Education*, 11(1), 1–14.

[5] Bickmore, B. R., Thompson, K. R., Grandy, D. A., & Tomlin, T. 2009. Science As Storytelling for Teaching the Nature of Science and the Science-Religion Interface. *Journal of Geoscience Education*, 57(3), 178–190.

[6] Bonsignore, E. 2011. Sharing stories "in the wild": a mobile storytelling case study. In *Proc. Human Factors in Computing Systems, (CHI 2011)*, ACM, 2011, 917-922.

[7] Bonsignore, E. 2010. *The Use of Storykit: Design Implications for Intergenerational Mobile Storytelling*. Tech Report HCIL-2010-31, HCIL, College Park, MD USA.

[8] Bouillion, L. & Gomez, L. 2001. Connecting school and community with science learning: real world problems and school–community partnerships as contextual scaffolds*. *Journal of Research in Science Teaching*, 38, 8, 878-898.

[9] boyd, d. 2007. Why youth <3 social network sites: the role of networked publics in teenage social life. *The John D. and Catherine T. MacArthur Foundation Series on Digital Media and Learning,* 119-142.

[10] Cahill, C., Kuhn, A., Schmoll, S., Pompe, A. & Quintana, C. 2010. Zydeco: using mobile and web technologies to support seamless inquiry between museum and school contexts. In *Proc. Interaction Design and Children (IDC 2010)*, ACM.

[11] Calabrese Barton, A. 2001. Science education in urban settings: seeking new ways of praxis through critical ethnography. *Journal of Research in Science Teaching*, 38, 8, 899-917.

[12] Calabrese Barton, A. 1998. Teaching science with homeless children: pedagogy, representation, and identity. *Journal of Research in Science Teaching*, 35, 379-394.

[13] Chinn, C. & Malhotra, B. 2002. Epistemologically authentic inquiry in schools: a theoretical framework for evaluating inquiry tasks. *Science Education*, 86, 2, 175-218.

[14] Chinn, C. A. & Malhotra, B. A. 2001. *Epistemologically Authentic Scientific Reasoning*. In K. Crowley, C. D. Schunn, & T. Okada (Eds.), Designing for science: Implications from everyday, classroom, and professional settings, (pp. 351-392). Mahwah, NJ: Erlbaum.

[15] Clegg, T., Gardner, C., & Kolodner, J. 2010. Playing with food: turning play into scientifically meaningful experiences. In *Proc. International Conference of the Learning Sciences*, (*ICLS 2010)*, ISLS.

[16] Clegg, T., Gardner, C. & Kolodner, J. 2011. Technology for supporting learners in physically demanding out-of-school learning environments. In *Proc. Computer-Supported Collaborative Learning (CSCL 2011)*, ISLS.

[17] Clegg, T. & Kolodner, J. 2007. Bricoleurs and planners engaging in scientific reasoning: a tale of two groups in one learning community. *Research and Practice in Technology Enhanced Learning*, 2, 3, 239-266.

[18] Corbin, J. & Strauss, A. 2008. *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. Thousand Oaks, CA: Sage Publications.

[19] Druin, A. 1999. Cooperative inquiry: developing new technologies for children with children. In *Proc. Human Factors in Computing Systems, (CHI 1999),* ACM.

[20] Fleck, M., Frid, M., Kindberg, T., O'Brien-Strain, E., Rajani, R. & Spasojevic, M. 2002. Rememberer: a tool for capturing museum visits. *UbiComp 2002: Ubiquitous Computing*. Springer Berlin/Heidelberg.

[21] Franckel, S., Bonsignore, E. & Druin, A. 2010. Designing for children's mobile storytelling. *International Journal of Mobile Human Computer Interaction (IJMHCI)*, 2, 2, 19-36.

[22] Gardner, C. M., Clegg, T. L., Williams, O. L. & Kolodner, J. L. 2006. Messy learning environments: busy hands and less engaged minds. In *Proc. International Conference of the Learning Sciences (ICLS 2006)*, ISLS.

[23] Gleason, M. E. & Schauble, L. 1999. Parents' assistance of their children's scientific reasoning. *Cognition and Instruction*, 17, 4, 343 - 378.

[24] Greenhow, C. 2011. Youth, learning, and social media. *Journal of Educational Computing Research*, 45, 2, 139-146.

[25] Grobstein, P. 2005. Revisting science in culture: science as story telling and story revising. *Journal of Research Practice*, 1, 1, 1–18.

[26] Hsi, S. & Fait, H. 2005. Rfid enhances visitors' museum experience at the exploratorium. *Commun. of the ACM*, 48, 9, 60-65.

[27] Ito, M. 2005. *Mobile Phones, Japanese Youth, and the Re-placement of Social Contact*. London: Springer.

[28] Jenkins, H., Clinton, K., Purushotma, R., Robinson, A. J., & Weigel, M. 2006. *Confronting the Challenges of Participatory Culture: Media Education for the 21st Century.* Chicago, IL: MacArthur Foundation.

[29] Johnson, B. D. 2011. *Science Fiction Prototyping: Designing the Future With Science Fiction*. San Rafael, CA: Morgan & Claypool.

[30] Kuhn, A., Cahill, C., Quintana, C. & Schmoll, S. 2011. Using tags to encourage reflection and annotation on data during nomadic inquiry. In *Proc. Human Factors in Computing Systems, (CHI 2011)*, ACM.

[31] Kuhn, A., Cahill, C., Quintana, C. & Soloway, E. 2010. Scaffolding science inquiry in museums with Zydeco. In *Proc. Human Factors in Computing Systems, (CHI 2010),* ACM.

[32] Kuhn, A., McNally, B., Schmoll, S., Cahill, C., Lo, W., Quintana, C. & Delen, I. 2012. How students find, evaluate and utilize peer-collected annotated multimedia data in science inquiry with Zydeco. In *Proc. Human Factors in Computing Systems, (CHI 2012)*, ACM.

[33] Latour, B. 1987. *Science In Action*. Cambridge, MA: Harvard University Press.

[34] Lee, O. & Fradd, S. H. 1998. Science for all, including students from non-english-language backgrounds. *Educational Researcher*, 27, 4, 12-21.

[35] Martin, B. & Brouwer, W. 1991. The sharing of personal science and the narrative element in science education. *Science Education*, 75, 6, 707-722.

[36] Milne, C. 1998. Philosophically correct science stories? Examining the implications of heroic science stories for school science. *Journal of Research in Science Teaching*, 35, 2, 175-187.

[37] Osborne, J., Collins, S., Ratcliffe, M., Millar, R. & Duschl, R. 2003. What "ideas-about-science" should be taught in school science? A Delphi study of the expert community. *Journal of Research in Science Teaching*, 40, 7, 692-720.

[38] Papadimitriou, C. H. 2003. MythematiCS: in praise of storytelling in the teaching of computer science and math. *SIGCSE Bull.*, 35, 4, 7-9.

[39] Quinn, A., Bederson, B., Bonsignore, E. & Druin, A. 2009. *StoryKit: Designing a Mobile Application for Story Creation By Children And Older Adults*. Tech Report HCIL-2009-22, HCIL, College Park, MD USA.

[40] Rogers, Y. & Price, S. 2008. The Role of Mobile Devices in Facilitating Collaborative Inquiry in Situ *Research and Practice in Technology Enhanced Learning*, 3, 3, 209-229.

[41] Rogers, Y., Price, S., Randell, C., Fraser, D. S., Weal, M. & Fitzpatrick, G. 2005. Ubi-learning integrates indoor and outdoor experiences. *Commun. of the ACM*, 48, 1, 55-59.

[42] Rosebery, A. S., Warren, B., & Conant, F. R. 1992. *Appropriating Scientific Discourse: Findings from Language Minority Classrooms*. UC Berkeley: Center for Research on Education, Diversity and Excellence. Retrieved from http://www.escholarship.org/uc/item/9286r4x9.

[43] Sadik, A. 2008. Digital storytelling: a meaningful technology-integrated approach for engaged student learning. *Educational Technology Research and Development*, 56, 4, 487-506.

[44] Scardamalia, M. 2002. Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.) *Liberal Education in a Knowledge Society*, 67-98. Chicago: Open Court.

[45] Wyeth, P. & MacColl, I. 2010. Noising around: investigations in mobile learning. In *Proc. Interaction Design and Children (IDC 2010),* ACM.

[46] Yip, J., Clegg, T., Bonsignore, E., Gelderblom, H., Lewittes, B., Guha, M. L. & Druin, A. 2012. Kitchen Chemistry: supporting learners' decisions in science. In *Proc. International Conference of the Learning Sciences (ICLS 2012)*, ISLS.