

Designing Mobile Digital Library Services for Pre-engineering and Technology Literacy*

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The potential of new developments in mobile technology, with capabilities for anytime, anywhere wireless access, to affect pre-engineering education and technical literacy at the K-12 level remains poorly understood. Mobile access to digital libraries provides unique opportunities for leveraging valuable experiences outside of the classroom. This paper presents a user needs analysis of teachers, students and parents with regard to understanding the potential of such mobile digital library services to enhance science and technology learning in informal environments for students in U.S. grades 4–5 and middle school. To study this area we discuss a methodology at the intersection of design and research that borrows from qualitative research methods and traditional user-centered design, together with frameworks for translating qualitative data into concrete user needs. We present a summary of twelve need “themes” that emerged from the analysis together with recommendations for how these themes inform the development of a mobile digital library infrastructure and its digital learning resources. The recommendations are illustrated on an informal learning scenario intended for a pre-engineering exercise using resources from the NEEDS engineering education digital library at www.needs.org.

Keywords: mobile learning; engineering education; mobile devices; digital library; mobile library; K-12; informal learning; science education

INTRODUCTION

MOBILE DEVICES such as modern cell phones, smart phones and PDAs (Personal Digital Assistants) have the potential to provide K-12 students and teachers with access to learning resources untethered from the constraints of traditional school infrastructures; as yet, this potential is poorly understood. With nearly 85% of a student's time spent outside of the classroom, there is abundant opportunity to transform daily events into meaningful learning opportunities that contribute to and complement a student's overall education [26, 34].

Mobile learning provides an excellent opportunity to expose students to everyday technologies in informal settings and link to pre-engineering curricular material and related math and science concepts. “Exposure to technological concepts and hands-on, design related activities in the elementary and secondary grades are the most likely ways to help children acquire the kinds of knowledge, ways of thinking and acting, and capabilities consistent with technological literacy” [31].

Our research focuses on the opportunities provided by mobile devices to enhance pre-engineering education at the elementary level and technology literacy for all students. At this early stage,

students learn the fundamental building blocks of engineering through math, science and technology learning [25]. During these early years, pre-engineering education often consists of real world observations of scientific principles as embodied in everyday technologies, enhanced by experiential learning exercises outside of the traditional school setting. Out-of-classroom learning experiences can offer students information learning opportunities to engage in the synthesis of science and technology, to use their inquiry skills, and to participate in active discourse with peer learners. Learning in context can help student learn by providing contextual clues and by allowing students to leverage personal experience to make strong connections with material [4]. According to one study [12], students with enriched informal learning environments had significantly higher scientific reasoning abilities than those with impoverished informal learning environments. To further support informal learning situations, a key potential of mobile devices is to allow students to remotely access relevant and related learning resources.

Several recent, well-publicized successes have concerned the use of the iPod [2], the popular portable music player, in higher education, to provide educational media outside of the classroom environment at times convenient to the students [36]. The iPod has also been employed to help elementary school students in learning

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vocabulary or the alphabet with material they can listen to at home. In this study, we wish to understand the potential for enhanced science and engineering learning in contexts where the subject matter is complemented through experiences outside of the classroom. As we will present, the context of elementary school field trips is sufficiently distinct from that of higher education students listening to lectures such as to provide a broader range of design challenges and infrastructure requirements.

Consequently, we define mobile learning in this context as the use of portable, electronic devices to facilitate education in informal or semi-structured settings. We define the mobile library as the information access infrastructure to support learning in these same settings—it is a mobile extension of the digital library.

Some of the most immediate applications for mobile learning are seen with biology, ecology, geography, geology, and history, subjects that are intimately tied to the physical environment. Applications have been developed that leverage the mobility of new devices to access learning content and resources by location, for example using GPS technology to identify landmarks, habitats, animal sightings, and even tourist information [6, 27, 35]. However, we are primarily interested in the possibilities of mobile devices to support science learning, particularly as it relates to development of engineering skills and technology literacy. We are collaborating with several organizations that focus on bringing pre-engineering education to K-12 audiences [1, 5, 37].

Mobile devices provide the ability to access remote resources untethered from the classroom, a key opportunity for authentic exposure to real-world engineering problems, but an infrastructure is necessary to store, serve, maintain and host these resources. Within the domain of science, technology, engineering, and mathematics (STE&M) education digital libraries, such as the SMETE (STEM Education; www.smete.org) or NEEDS (National Engineering Education Digital-library System; www.needs.org) digital library at UC Berkeley, are quickly becoming mainstream tools, addressing this need at a range of educational levels [7, 21]. These digital libraries provide educators with access to digital resources and allow educators and students to share resources, rate resources and interact as a community. Engineering education is specifically addressed at the K-12 level by the Teach Engineering digital library. Teach Engineering provides “teacher-tested, standards-based engineering content” and resources to be used in the classroom. The possibilities of making these and other resources available outside the classroom is a primary motivation for this paper.

Extending the reach of engineering digital libraries via mobile learning is the key concept underlying this project [8]. Figure 1 shows the theme page from the NEEDS digital library, high-

lighting a collection of resources focused on mobile learning.

To develop the mobile library concept, we conducted a study to understand the needs of potential mobile library users, namely teachers, students and parents, with regard to out of the classroom activities, new technologies, and the constraints and opportunities of using mobile devices. This user needs study resulted in infrastructure design recommendations to support appropriate, robust and sustainable mobile digital library services. In addition to infrastructure recommendations, the paper provides a guide for educators when developing pre-engineering and technology literacy educational resources and activities to be used by and incorporating mobile devices.

This paper first presents the methodology used to approach this development and the data collection methods employed, followed by the analysis techniques and outcomes of the study. It finishes with implications for the development of a digital infrastructure and the authors’ conclusions.

RESEARCH SYNOPSIS

Design methodology

Studying the intersection and possibilities of education and mobile technology requires an approach that is based on both research and design. In this study therefore we drew heavily from methods from qualitative research from the social sciences in addition to user-centered and empathic design methodology [13, 20].

Rather than adopting a technology-centric design approach we employed a user-centered approach with the goal of first understanding the needs and values of students, educators and parents. The methodology was rooted in close observations of these three primary stakeholders in educational environments invested in science, math or technology. This approach allowed the goals of the potential user groups to directly influence the development of applications, hardware and infrastructure for the delivery of learning resources. Taking the issues and concerns of real students, parents and educators in their natural settings provided a richer depth and breadth of understanding of important issues than a technology-centric approach can provide. This approach was effective in that it combines the rigor and depth of analysis afforded by qualitative research methods together with analysis and a needs-oriented approach leading to actionable design recommendations.

We followed a modified version of Owen’s original four-stage design framework as shown in Fig. 2 [28, 29]. This framework moves from concrete observations of the world in the form of user behavior and words, through analysis, using a number of possible frameworks including coding, metaphors, typologies or cultural frames. Owing to



Fig. 1. NEEDS digital library theme page for Mobile Learning resources.

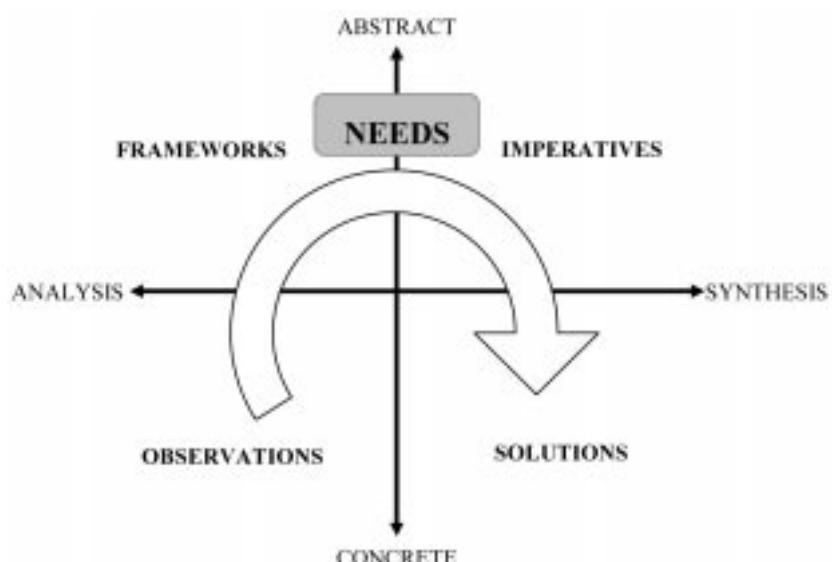


Fig. 2. Design framework followed (modified from Owen [1, Error! Reference source not found.])

the research nature of this study, we applied strong qualitative methods for both the Observation and Frameworks parts of the design cycle. Drawing from the analysis we can identify needs at different levels of specificity. These needs are then used to generate design imperatives in the form of solution metaphors, or design principles. Finally, these imperatives are used to generate solution concepts and begin an iterative prototyping and evaluating cycle.

This paper focuses on the first three stages of the cycle and concludes with design recommendations for infrastructure suggested from a needs hierarchy (at the top of the cycle in Fig. 2) for use in the final design solution stage. The presentation of a needs analysis has the advantage of wider transferability of the study despite the non-homogenous nature of the sample population.

Study context

Our study took place in the context of public schools and programs within the greater Bay Area of California. Our focus was on elementary and middle school students, primarily U.S. grades four and five, approximate ages 9–11. This is a critical age where students make decisions that will either enable or limit their abilities to get admitted to a competitive engineering program. We primarily investigated science and math education within the context of out-of-the-classroom activities. Despite this relatively targeted study context we found a wide range of situations in terms of school attitudes, population demographics, ability and familiarity with technology, and available resources.

DATA COLLECTION

We selected three primary qualitative research strategies to enhance our understanding of the needs and values of the potential users of mobile technologies for learning: observations, teacher interviews, and student workshops.

Observations

Individual researchers from the project documented seventeen site visit observations of local science activities for elementary school students. These science activities included summer camps, science museums, nature centers and school field trips. Our observation followed an evolving observation protocol that included: interactions of students with educational design elements such as exhibits and lesson plans; individual and group behavior; engagement and questioning behaviors; and physical constraints and activities. These observations allowed researchers to witness first-hand how the target groups interact with their out-of-the-classroom educational environments.

Teacher interviews

We conducted nine formal, semi-structured interviews with schoolteachers and science coordi-

nators in different public elementary schools ranging from 40 to 90 minutes. Interview topics included teacher flexibility in creating lesson content, teacher and student engagement, activities outside the classroom—field trips in particular, and both teacher and student experience with mobile and traditional technologies. The teachers were recruited on a voluntary basis from Berkeley and Oakland, California. The interviews provided insight into current teacher relationships with students, educational strategies and technology.

Student workshop

We conducted a two-hour workshop with eight students as an exploratory session to observe behavior, and facility and engagement with several key technologies and to learn about student opinions and feelings toward field trips and math, science and technology learning. The session covered students' experience and familiarity with digital cameras, cell phones and PDAs, followed by time for free experimentation with both digital cameras and PDAs. The workshop format provided an effective opportunity to learn about how the students interact with the hardware of mobile technology. The workshop also aimed to provide a platform for cooperative design with the students themselves as design partners [9–11]. Cooperative design is itself a part of the broader framework of participatory design (see for example [33])

ANALYSIS

We designed analysis methods to effectively and efficiently share content and findings from each of the three qualitative research strategies among the seven-person research team.

Data from the observations of local science museums and science camps were captured through note taking and discussions. After reviewing the observation field notes, we developed a codebook that identified a number of codes, or tags for certain categories of important and useful information [13, 23]. Two researchers independently coded the observation notes and the key findings and data codes were extracted and shared in multiple discussions. We then reviewed the field notes again and coded the data by tagging the relevant portions.

Each of the teacher interviews was audio recorded and then transcribed. Through discussion, we extracted key findings, data codes, and interview quotes after reviewing the transcriptions. We followed an iterative approach to code development, refining and distilling codes.

The student workshop was captured on video together with the drawings made and photographs taken by the students. In order to effectively process the interview data we performed a rapid analysis of the workshop video data by assigning different foci for each team member and capturing

the real-time observations and analysis of the research team as the video was run.

Analyzing coded data

To prepare for analyzing the coded data, we first separated out the key passages into code categories. Each researcher read through a different set of code categories and attempted to identify the underlying needs of teachers and students. In addition, we also identified any particularly striking information and interesting or conflicting anecdotes that revealed the presence of social norms or hinted at underlying tensions.

We then attempted to place the needs that were found into a framework of a needs hierarchy [30]. This hierarchy identifies four different types of needs: common, contextual, activity, and qualifier. A common need is one that is virtually universal, shared by all; a contextual need is one that is shared by a certain group of people who share similar backgrounds or characteristics; an activity need is one that expresses the need to perform a certain activity; and a qualifier need expresses the need to perform a certain activity in a certain way. Using this framework, we categorized each of the needs that emerged from the data collected. Asking why a particular need exists allows the researcher or designer to trace back to the common underlying need. By asking how a need could be fulfilled, it is possible to identify the more specific and actionable needs that lead more immediately towards concrete solution directions. In order to better illustrate the process a photograph of part of the full table of needs is shown in Fig. 3.

After placing the needs in a hierarchical framework, we then grouped them into clusters by searching for common themes. From this exercise, we were able to identify a dozen need themes. A simplified example of a need theme that emerged, 'Adapting to and adopting technology', is

arranged according to the need hierarchy in Table 1.

Need themes are typically more complex than the example shown, as multiple lower level needs tend to satisfy higher level needs; the hierarchy tends to have more lower level needs than the higher level needs. The remaining themes identified, including, for example, Personal relevance, Wellbeing, and Equal access, are discussed in the outcomes section. This framework was then used by the group to generate forward-looking design recommendations for a mobile library infrastructure that supports pre-engineering and technology literacy educational activities.

RESULTS

The primary goal of this study concerns the advice to developers of K-12 engineering resources for mobile devices and mobile infrastructure to consider the broad range of contexts of use. The following themes were identified through use of the needs hierarchy framework and born directly out of observations, interviews and student interaction. Key elements from each need theme that emerged from our study are summarized below.

1. Connect
2. Personal Perspective
3. Adapting to and Adopting Technology
4. Equal Access
5. Capture
6. Organizing
7. Wellbeing
8. Covering Material
9. Assessing Understanding
10. Cater to All
11. Personal Growth of students
12. Personal Development



Fig. 3. Illustration of needs hierarchy and clustering analysis process.

Table 1. Need hierarchy relating to the theme of 'Adapting to and adopting technology'. Such a need hierarchy was constructed for each need theme

Need type	Definition	Need theme: Adapting to and adopting technology	
Common	Cultural need shared by everyone	Need to have confidence in what you do	Ask Why
Context	Situational need driving subsequent actions	Need to trust the technology you work with	
Activity	Direct need fixing a problem or replacing what is missing	Need to be able to troubleshoot technology problems	
Qualifier	Specific needs satisfying interactions	Need to troubleshoot technology problems without external help	Ask How



Connect—Activities and content covered in out of the classroom activities must be, in some way, connected back to the classroom experience environment.

For the students this provides continuity of experience and learning while also increasing engagement and motivation to participate. For the teacher this increases the value of the field trip within a learning context justifying the time spent. One effective example we observed involved students going on a hike after learning about insect metamorphosis, morphology and vocabulary to discover real insects for themselves.

Personal relevance—Establishing a personal connection allows students to develop a relationship to the educational material from his/her perspective, the aim being to motivate and inspire educational curiosity.

Students are more engaged in activities that have a personal meaning to them and this is especially important during science field trips, where the students' behavior is not strictly dictated by the classroom environment and where a range of stimuli exist. Activities and resources then should be sure to provide ways for a teacher, and the students themselves, to make the resources relevant to their lives. The educational content itself may be immediately relevant, such as discussing local weather patterns. Educational content can also be made relevant by making explicit connections to students' experiences or by making the educational content a part of the students' experience. For example, we learned of an activity in which students designed packaging for a candy box. The teacher later introduced multiplication and related the math concepts directly back to the

packaging design project in which students have invested personal energy. Another effective example at a local science museum simply involved a video camera that projected students directly into the moon environment on a television screen.

Adapting and adopting technology—Teachers need ongoing assistance both adapting to and in adopting new technologies.

In order to effectively leverage new teaching technologies in their instructional activities, teachers need to be able to have complete confidence in the tools they are using and in the associated activities. As an illustration of this point, on many occasions, we observed technology in the classroom that was largely unused because it was broken or it was perceived to be unhelpful and difficult to operate.

Teachers need an understanding of new technology tools at a range of levels. Educational technology and tools must be accessible and reliable at the same level as tape recorders or video recorders. In order for this to happen new tools should employ educational metaphors, such as a library or a quiz, that are well understood by teachers. Relating new tools to existing non-educationally restricted technologies such as film cameras and encyclopedias may also prove useful.

At a practical level teachers need to be confident in the functioning and troubleshooting aspects of new technologies, and these technologies must be as reliable as possible. Training and support in the first uses of new tools is very important. Even so, it was found that training time, particularly for new initiatives, was very hard to come by. Ensuring that technology uses well-understood models and is reliable and simple to troubleshoot goes a long

way to minimizing training required and allowing teachers to have confidence in the new tools they are using.

Foremost, teachers need to feel that the new tools and technologies are providing their students with a genuine educational benefit—allowing the teachers to achieve learning outcomes that they were not able to before or that had previously proved more difficult. For this reason new technologies must provide new opportunities, such as capabilities for capturing birdcalls or increased student interest and engagement.

The design of the devices themselves can also provide significant opportunity to enhance confidence in the use of the technology. We observed repeatedly that the devices currently available fell well short of basic usability concerns when put into the hands of both students and teachers in a field trip environment. For example, students using digital cameras would often unintentionally change the mode to high-resolution photographs and fill up the available memory, or set the camera to flash, draining the battery, or accidentally take movies instead of photographs. There are tremendous opportunities available for the appropriate design of mobile devices for use by elementary and middle school level students.

Equal access—All students must have equal (balanced) access to new technologies.

Equitable allocation of time and resources amongst students is important for teachers in maintaining a consistent message to students. While this does not necessarily entail that all students are in possession of their own device, as some initiatives advocate [14], it does require conscientious procedures for the sharing of resources among students. Mobile devices do, however, provide an exciting possibility to inexpensively provide each individual student with their own device as compared with bulkier and more expensive technologies such as laptop and desktop computers.

Balanced access to new technologies is also a function of the technology's physical design in taking into account varying skill levels and aptitudes with digital devices. Additionally, the technologies, digital resources and user interfaces themselves must also consider the needs of students with a range of physical needs and limitations. Accessible designs may include the use of larger fonts, even on small screens, for visually impaired students, or large buttons for students with impaired motor coordination.

Capture—New technologies must provide capabilities to capture data and notes while away from the classroom.

Mobile devices can capture authentic educational multimedia data, in context, that have previously been unavailable. Data captured in context allows for sharing and remembering experiences upon return to the classroom. The very act of data capture

can also enhance the learning experience. For example, instructing students to take photographs of instances of friction requires students to selectively choose and evaluate different scenarios for inclusion in the collection of images illustrating friction. Using multiple forms of data capture, for example, supporting photographs with audio recordings and student notes can assist students and teachers in seeing the whole picture of a learning experience.

The potential scenarios for capture include student note-taking and responses to questions, sketches, photographs, audio recordings, video, and data from “probeware” [3], physical objects and more. We observed an effective use of GPS (Global satellite Positioning System) data to record the location of specific items during a hike; this was then shared and examined on return to the classroom.

Organizing/Structuring—Managing logistics and bureaucracy were universally viewed by teachers as the primary obstacles to conducting successful field trips.

For teachers, out-of-the-classroom activities represent the significant additional burden of organization and coordination including administrative-permission, parent-permission, payment, parent volunteers and transport to and from field trip destinations. Software and mobile devices do have a small potential to decrease this organizational burden on teachers, through providing local maps and information, including bus routes, for example. However this is not the primary benefit. Considering the needs of teachers, what is most important is that any new tool or technology provides no additional burden or inconvenience; increased effort or thought required on behalf of teachers serves only to slow and decrease technology adoption.

Wellbeing—The wellbeing of students is a primary concern of teachers whenever outside of the classroom.

It is important that mobile devices do not provide additional opportunities for students to get hurt, or enhance the likelihood of students causing damage to the visited locations. Mobile devices need to consider the physical scenarios established as students adopt mobile devices, for example, looking where they are walking or heading. Wellbeing also extends to any equipment used outside the classroom—devices must be robust, not cause the concern of damaging the device, or interfere with the activity. For example, although PDA styluses provide an intuitive way to interact with devices for many, the benefit is largely diminished if attention is required from the teacher to ensure they are not lost. Another example of a problematic design is shown in Fig. 4 where a student is struggling to hold and read a PDA while operating an interactive science experiment at the Exploratorium in San Francisco.



Fig. 4. Children using PDA at interactive science museum.

Covering educational material—When adopting new technologies and educational resources an important consideration is their integration with existing educational content requirements.

Local and national educational standards provide restrictions to the content that a teacher must cover within a limited amount of time. Resources that do not map or relate to the required educational standards will limit adoption by teachers. Resources and activities that are closely tied to educational standards and that provide teachers with capabilities to adapt or modify them to meet local standards will greatly increase the ease of adoption by teachers. This is one of the motivations for aligning digital library resources to state and national standards, such as is being done by the TeachEngineering digital library [37] at www.teachengineering.com.

Assessing understanding—Assessing student understanding from out-of-the-classroom activities such as field trips remains problematic for most teachers.

While many teachers employ some form of recap and post activity discussion they acknowledge that the kind of learning that is gained from hands-on field trips and visits remains hard to assess. Providing opportunities for teachers to increase their abilities for assessment is a promising avenue for the future development of mobile device and resource development. For example, digital photographs, from digital cameras, PDAs or camera phones, provide opportunities for assessment with younger age groups where traditional written or even verbal assessment confuses writing and abilities with understanding gained from activities.

Cater to all—Flexibility in learning preferences

Whenever possible, activities and resources should provide opportunities accessible for a range of different learning styles: visual, auditory and kinesthetic. All teachers whom we spoke with discussed their belief that students learn material in different ways and that it is best to try to adapt to meet the different needs of their students. While

field trips generally provide most support for the kinesthetic learning style, the flexibility of digital resources presented on mobile devices provides the opportunity to provide different means of exploration for each student. Visual learners could study photos or concept maps, auditory learners can listen to narratives, site staff and read text, while kinesthetic learners can explore hands-on the environment they are in.

Personal growth of students—Resources, where possible, need to help articulate and illustrate the personal growth of the students as they develop and as they accumulate knowledge and understanding.

Teachers discussed the value in motivating students through illustrating the progress they have made. The ability to illustrate to students the gaps in their current knowledge, and also the gaps they have filled in over time is a powerful teaching tool. Additional media, such as photographs, provide useful references that enable teachers to show students their own progress and a record of the activities they have performed. The longevity and ease of access to digital records allow the opportunity to provide students with a shareable and permanent record of their progress through school. This is of particular advantage in the earlier grades.

Personal development—Providing opportunities for the personal and social development of students within educational settings.

In many cases personal development was accomplished by engaging students in discussions relating to the students' relationships with each other and learning to work and live as a well functioning social group. Other means included discussions of the relevance of the lessons being learned to future activities beyond school, or simply expanding students' spheres of experience through field trips to places where they would normally have no opportunity to visit. While digital resources and mobile devices may not play a key role in enhancing the teacher's ability to help students' personal development it is important that they do not obstruct it.

IMPLICATIONS FOR DEVELOPMENT

A primary objective of the study has been to develop and implement methods to achieve informed design within these complex circumstances of multiple stakeholders, established practices, evolving technologies, large individual differences and a myriad of constraints. This section discusses the recommendations for the development of digital resources for engineering education accessible from mobile devices and, primarily, an infrastructure to combine the two. The recommendations 1–12, listed above, were born out of the need themes identified in the previous section. While the

Table 2. Development implications for a mobile library infrastructure

Theme	Infrastructure recommendation
1. Connect	A mobile library infrastructure for K-12 engineering education should provide support when possible to assist students in connecting material learned outside the classroom with material learned inside. One way to do this is to provide the capability of linking standard educational activities and material with mobile resources for outside the classroom activity.
2. Personal relevance	Provide capabilities for students to upload and track their own work. Have the ability to archive the personal history of resources used by students.
3. Adapting and adopting technology	Keep interfaces simple by eliminating or hiding non-critical options. Use common metaphors for interfaces and functionality to ease transition to the new system. Technology must provide feedback for foreseeable failures such as charging of batteries, full memory cards and the like. The Google search engine [15] was commonly used within classrooms and is therefore a familiar model to emulate. Google Image search [16] was also a popular tool within schools. Search, and image search in particular, is an understood and accepted modality of computing interaction for both students and teachers. Providing easy access to Google Image search would be useful. A “point person” for technology maintenance and championing is not always possible at all schools. Developed tools must therefore be simple enough to be used by non-technology savvy teachers. Despite best intentions, most teachers will not have the time or the resources to undertake technical training to use and manage devices. Given these constraints, the imperative is on the designers of the mobile library, not the teachers, to make information both accessible and relevant. Training guides and support must be in an easily accessible and efficient format, such as video, to help teachers begin to use the tools
4. Equal access	Providing an infrastructure to support digital resources on mobile devices seems an effective way to provide content to a wider range of students than is possible through classroom computers alone. Resources and interfaces must be accessible to disabled students and teachers—support should be provided, for example, for larger fonts and technologies such as screen readers.
5. Capture	Digital photographs seem to be one of the most promising initial impacts for a mobile library. A mobile library infrastructure should support the uploading of standard digital photo formats. The transfer of captured data towards a usable form for analysis or within a class should be simplified as much as possible. Any infrastructure must therefore provide a streamlined and fluid transfer of captured data to practical formats. Direct emailing of photos from camera phones to photo blogs is a useful analogy that could be extended to captures from field trips. Captured data may take a variety of forms. An infrastructure should be able to support multiple file formats including those for photos, videos, text and other documents.
6. Organizing/ Structuring	Mobile engineering digital library infrastructure could provide basic facilities to assist teachers in organizing field trips, such as keeping track of student participation, resources needed and expenses. Mobile engineering digital library infrastructure could also provide simple tools for keeping track of mobile devices that are in use on any field trip. Setting up and access to resources from the mobile devices themselves must be kept as simple as possible. Reducing the initial investment barrier to use a resource on twenty or more mobile devices is a key factor in their potential adoption. To provide teachers with a gauge of the relevance and appropriateness of resources before using them with students, an infrastructure could provide the capabilities to share usage stories with other teachers.
7. Wellbeing	The devices themselves must be made as robust as possible to survive the rigors of multiple uses by students outside the classroom. There remains tremendous potential for the design of educational mobile devices for elementary and middle school students that minimize the technical interactions required to focus on the educational benefits. When possible devices should be designed to be hands-free when not in use to enable students to interact physically with their environment as they would without them.
8. Covering educational material	Working within the state curriculum guidelines and with accepted learning strategies (e.g. GLAD, Guided Language Acquisition Design [32] will improve the prospects of acceptance and success. Some states are even developing technology standards [25]. An infrastructure should provide the possibility to organize and catalogue resources, making explicit their relationships to state or national standards. Encouraging authors of resources to provide content that is flexible in its application and adaptable by teachers to local standards.
9. Assessing understanding	Opportunities exist for learning resources on mobile devices to assist in learning assessment of science activities when students are outside the classroom. A mobile engineering digital library infrastructure for K-12 should provide areas accessible only to teachers to allow them to manage students and material. There is the possibility to integrate grading schemes that are verifiable directly while out of the classroom. Photographs provide an effective, durable and sharable means for assessing learning outcomes, especially in earlier grades. Providing assessment tools that support the integration of additional media such as photographs may provide exciting opportunities for improved grading. Photographs also provide particular benefit for science and engineering education that does not primarily concern verbal and writing skills.
10. Cater to all	The potential of mobile devices to support media such as photographs, audio and video leads to the requirement of a mobile digital library infrastructure to support and provide access to potentially large files. There is a need to cater to multiple student abilities, in terms of language and learning abilities. In particular, language differences can be viewed as an opportunity in bilingual schools; creating an infrastructure that supports language development via science and engineering learning may lead to stronger support and ultimate acceptance.
11. Personal growth of students	Providing the capabilities for students to access their past history of resources and submissions would allow students to better track their progress. Automatic versioning for multiple file submissions would streamline the process of file management for both students and teachers.
12. Personal development	Providing the option to submit resources not directly related to science, math or technology would enable teachers to also provide lessons in personal social development when necessary. A mobile library infrastructure should provide support for sharing and viewing other students submitted content. Providing access to content promotes discussion and peer learning [22].

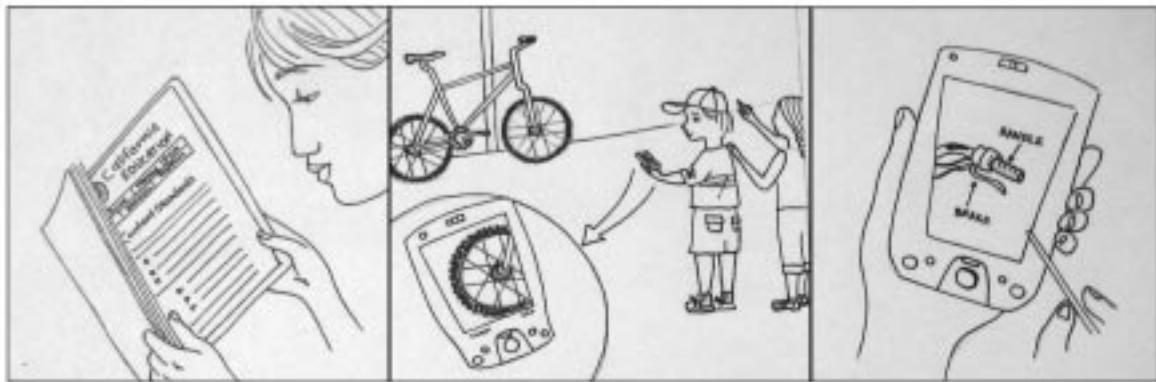
recommendations vary in their specificity the underlying principles are of more general applicability as shown in Table 2.

DEMONSTRATION USE SCENARIO

In this section we present a scenario that incorporates the needs themes identified above with a

new educational approach made possible through the use of mobile devices and the mobile digital library.

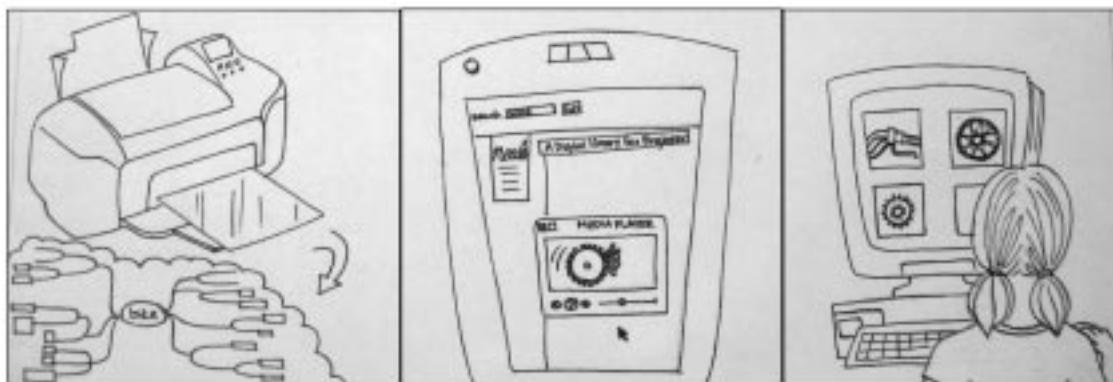
The scenario in Fig. 5 was designed to satisfy the relevant need themes that were identified in the previous sections. The material is connected to material that the teacher has been covering in the classroom (Connect) and the activity effectively addresses material that the students need to cover



The teacher would like to introduce some fundamental concepts of mechanics with an engaging activity. She searches over the NEEDS digital library mobile collection and finds a lesson plan, such as those at Learning In Hand which uses mobile devices to get the kids involved in their environment.

The teacher distributes devices to the kids who, in pairs, look for simple mechanical machines, such as pulleys, levers, gears or kinematic mechanisms that they see in their environment. They take photographs of the mechanisms and record a description of how they think they work.

They jointly annotate on the screen the photo of the mechanisms they identified to label the moving parts.



When the students return to the classroom the teacher wirelessly prints out from the devices each of the photographs from the students. The students create a large MindMap of the photographs to sort them into different clusters such as linkages, cranks and gears.

To learn more about the different types of mechanisms the students search on the NEEDS digital library. They find a collection of Kinematic Models for Design and view animations of the mechanisms to understand them further.

The photographs and descriptions created by the students are synchronized with a desktop computer and are automatically archived and posted to the Internet accessible to the students, parents and teachers. This allows others to comment on the work and promote more discussion and linkages with the classroom curricula.

Fig. 5. Mobile learning scenario for pre-engineering.

for the educational standards (Covering material). The activity is given a personal relevance to students by searching for mechanisms that are in their immediate environment at home and in their lives (Personal perspective). The cheaper availability of PDAs allows the students to work in pairs with a device (Equal access) and the use of photographs brings elements of the environment back to the classroom (Capture). Preloaded software and a simple interface make the exercise easy to use by the students and simple to set up for the teacher (Adapting to and adopting technology, Cater to all) and the wireless printing and automatic archiving online help the teacher manage the assignments (Organize). Through the MindMapping activity and the online archive the teacher is readily able to assess the students learning from the activity (Assessing understanding) and the students are able to see their own growth when they look back at the work they did in later years (Personal growth). Finally, working in pairs and carefully considering their environment encourages peer learning and the Personal development of the students.

The scenario also illustrates how the use of mobile devices assists with technology literacy and engages the students. The mobility of the devices also effectively allows important pre-engineering topics to be discussed through motivating real-world examples. Finally, the design of the mobile digital library provides an effective means for the teacher to both plan an effective lesson for the students and the students themselves to extend their learning of hands-on concepts through accessing digital resources.

CONCLUSIONS AND SUMMARY

This paper discussed a mixed research and design study to perform a needs analysis for the design of mobile engineering digital library infra-

structure to support informal learning using mobile devices. We presented twelve key needs areas at different levels of specificity that should be taken into account for the design of digital resources and mobile digital devices to be used in pre-engineering education and technology literacy activities. While our study emphasized the importance of carefully considering the local differences and variation, even within a small geographic area, the needs are stated at multiple levels to allow future designers and researchers to use them to inform their projects. Based on this needs analysis we also provided recommendations towards the design and development of an appropriate infrastructure to support the creation, sharing and utilization of digital resources to support informal learning about science and engineering using mobile devices.

In addition to the specific outcomes of this work, the methods used may provide a useful framework to others. In this paper we presented a methodology that incorporated elements from both ethnographic research and contemporary user-centered design techniques and tools. In particular, we have developed techniques to rapidly and effectively deal with large amounts of context-specific, qualitative data. This combined methodology may provide assistance for future designers and researchers aiming to understand and design within such complex environments.

Finally, we presented a scenario that illustrates an effective use of mobile devices to support pre-engineering education and technology literacy. The scenario leverages the understanding of user needs developed through this study and the design of an infrastructure to enable it.

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