Evaluating the Impact of Small Screens on the Use of Scaffolded Handheld Learning Tools

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Abstract

By synthesizing research from User-Centered Design and Learner-Centered Design, four criteria are developed to assess the impact of small screens on the use of handheld learning tools: artifact organization, navigation, contextual awareness and information transfer. These criteria are combined with existing techniques for assessing the efficacy of software scaffolds. The result is a method for assessing both the design of scaffolds in handheld tools and the impact of small screens on students' use of handheld software. This method is used to assess the results of a classroom study where two eighth grade science classes used three scaffolded handheld tools to engage in concept mapping, online research and scientific modeling.

Introduction

The MaLTS (Mobile Learning Tools for Science) project explores the impact of small screens on the design and use of scaffolded handheld tools for science inquiry. Portable, wireless, handheld devices such as Palm OS or Pocket PC computers offer a number of benefits for learners: they are flexible enough to support a range of learning activities and learning styles; they are small enough to go with students into the context of the learning activity; and they are affordable enough to make it feasible for all students to have a truly personal computing device to support their own learning. A number of schools and districts are already experimenting with handheld computers as a model for providing each student with a personal learning tool

(Branigan, 2001; Bull, Bull, Garofalo, & Harris, 2002; Curtis, Luchini, Bobrowsky, Quintana, & Soloway, 2002; Levinson & Grohe, 2001; Soloway et al., 1999; Tinker & Krajcik, 2001; Trotter, 2001).

While there are clear benefits to using portable computers to support learning activities, these devices also have a number of constraints, most notably their playing card-sized screens. Although constraints such as limited battery life and processing power continue to improve with successive generations of these devices, screen size has not increased over time. On the contrary, as display resolution has increased screen size has actually decreased. Thus, in order to harness the benefits of handheld learning tools, it is important to understand the challenges of designing and using supportive educational software within the constraints of handheld screens.

This paper focuses on methods for assessing the design and use of scaffolded, handheld software to support students during science inquiry projects. Three handheld software tools were developed:

- ***Pocket PiCoMap:*** supports students in building and editing concept maps, which are a type of graphical outline
- ***ArtemisExpress:*** supports students in conducting online research
- ***Pocket Model-It:*** supports students in building and testing models of dynamic systems

These three handheld tools were assessed during a classroom study involving thirty-three students in two eighth grade science classrooms. Two aspects of this data were assessed:

- ***The design of each individual scaffold.*** This assessment looks at whether students can find and use a scaffold, and whether using the scaffold helps students engage in the supported task.

- ***The design of each overall handheld software tool.*** This assessment looks at whether the constraints of small handheld screens impact students' ability to use the handheld software to engage in the supported task.

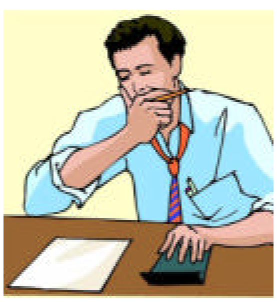
The remainder of this paper describes the Learner-Centered Design framework that underlies the MaLTS project, the design of the three handheld software tools, and the methods used to assess students' use of these tools during the classroom study.

Theoretical Framework

The MaLTS project draws on the framework of Learner-Centered Design (LCD), which is an approach to understanding and addressing the unique needs of learners. Within the LCD perspective, learners are defined as a group of novices who are trying to learn the content and work practices of a new domain (Quintana, Carra, Krajcik, & Soloway, 2002). In addition to lacking the background knowledge and experience of an expert in the domain, learners are also frequently characterized by a lack of motivation to work or to learn, disparate learning styles and paces, and shifting mental models that change as students learn more about the domain (Quintana, Krajcik, & Soloway, 2003). Table 1 depicts some of the key differences between the learners and experts.

To address learners' unique needs, LCD approaches often incorporate specialized supports, called scaffolds, into educational software and curriculum. The purpose of scaffolds is to provide learners with temporary assistance that allows them to mindfully engage in learning activities that would otherwise be too difficult or complex for the learners to complete without the support of the scaffolds (Bransford, Brown, & Cocking, 2000). Scaffolding techniques have been used successfully in a number of desktop tools to support diverse learning activities such as analyzing climate changes (Edelson, Gordin, & Pea, 1999) and working collaboratively to build a shared knowledge base of students' work (Scardamalia & Bereiter, 1996).

Table 1: Characteristics, Needs and Goals of Learners and Experts

Audience: Learners 	**Characteristics** • Lack knowledge of domain content and processes • Lack experience with task and tools • Often lack motivation • Lack of meta-cognitive skills • Heterogeneous population with different learning styles and paces • Changing mental models of the domain	**Needs** • Support for understanding domain content • Support for understanding inquiry process • Support for understanding how to use tools **Goals** • Learn about content of unfamiliar domain • Learn about work practices of unfamiliar domain • Complete an unfamiliar inquiry task
Audience: Experts 	**Characteristics** • Extensive knowledge of domain content and processes • Experienced with task • May be unfamiliar with specific tools for completing the task • Highly motivated • Familiar with meta-cognitive tasks • Relatively homogeneous population • Relatively fixed mental models of the domain	**Needs** • May need support for understanding how to use new tools to complete familiar task **Goals** • Complete a familiar task • May need to learn to use new tools to complete familiar tasks

Overview of Handheld Software

This section describes the three handheld software tools – Pocket PiCoMap, ArtemisExpress, and Pocket Model-It – developed as part of the MaLTS project.

Pocket PiCoMap allows students to use their handheld computers to create and share concept maps. Concept mapping helps students visualize their understanding of a topic in a concrete manner by writing down individual ideas inside circular nodes and connecting these ideas with directed arcs, which are labeled with the relationship between the two concepts. Figure 1 shows one students' concept map about sound. Concept mapping is a common classroom activity that helps students demonstrate their knowledge (Mintzes & Wandersee, 1998; Novak, 1998) and helps teachers assess changes in students' understanding over time (Nicoll, Francisco, & Nakhleh, 2001; Wallace & Mintzes, 1990).

Pocket PiCoMap includes several scaffolds to help students understand and engage in concept mapping activities. For example, the "Link Scaffold" is included to help students understand how the graphical relationships they create in their concept map are interpreted in English. For each graphical link between concepts in the map, the Link Scaffold provides a textual, English description of the full relationship. For instance, the relationship "Vibrations Make Sound" is displayed graphically in the concept map (shown in Figure 1) as a line between the concepts "Vibrations" and "Sound" while the link scaffold (shown in Figure 2) provides an English interpretation of this relationship.

The second handheld tool is ArtemisExpress, which supports online research. This activity includes a number of tasks such as developing a driving question (i.e., the topic or problem being investigated), finding relevant information, and synthesizing information from multiple sources (Abbas, Norris, & Soloway, 2002; Wallace et al., 1998). In ArtemisExpress these tasks are supported in different handheld workspaces:

- **Search:** students can conduct keyword searches and review relevant results
- **Driving Question:** students can store driving questions, relevant websites and notes
- **Share:** students can share driving questions and interesting websites with classmates
- **Tools:** provides past search results, a dictionary and thesaurus (to generate keywords)

One scaffold provided in ArtemisExpress is the driving question folder, shown in Figure 3, that allows students to record the driving question of their research and to collect relevant websites and notes. Figure 4 shows the Search workspace in ArtemisExpress.

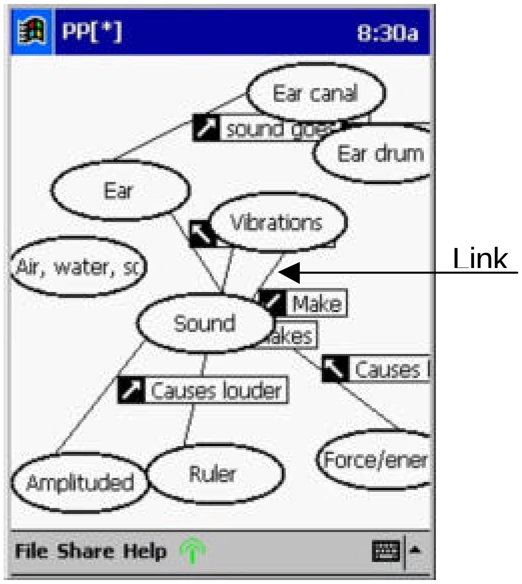


Figure 1: Concept map in Pocket PiCoMap

Figure 2: Link Scaffold in Pocket PiCoMap

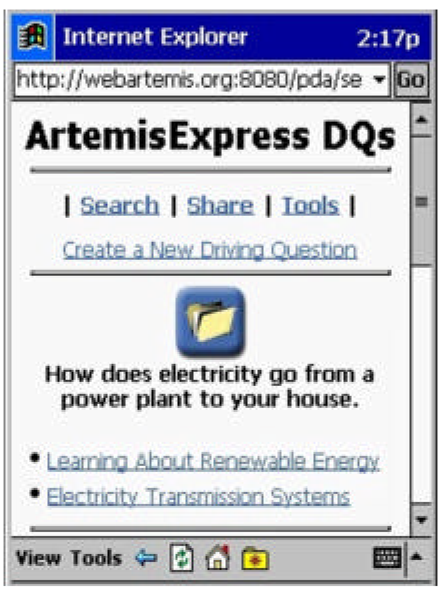


Figure 3: ArtemisExpress DQ

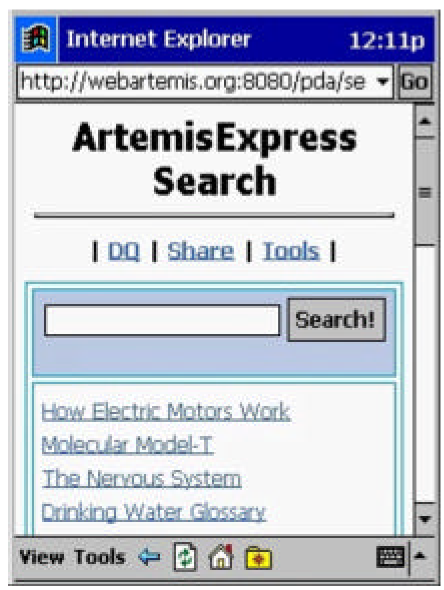


Figure 4: ArtemisExpress Search

The third handheld tool developed during the MaLTS project is Pocket Model-It. Pocket Model-It allows students to build and test models of complex systems, such as how changing nitrate or pH levels in river water impacts the fish population. Modeling allows students to explore the dynamics of complex systems and see the impact of changing factors within their models (Klopfer & Um, 2002; Metcalf, Krajcik, & Soloway, 2000; Stieff & Wilensky, 2002).

Pocket Model-It includes three main work “modes”: Plan, Build and Test. In Plan (Figure 5), students add objects to their models; for instance, a model about hearing might include the object “sound”. In Build (Figure 6), students add factors (also called variables) to describe their objects; for example, they might add a “pitch” factor to the “sound” object. Students also create relationships between factors in the Build workspace. Finally, in Test (Figure 7), students simulate the dynamic behavior of their model, changing factor values to observe the consequent impact on the rest of the system.

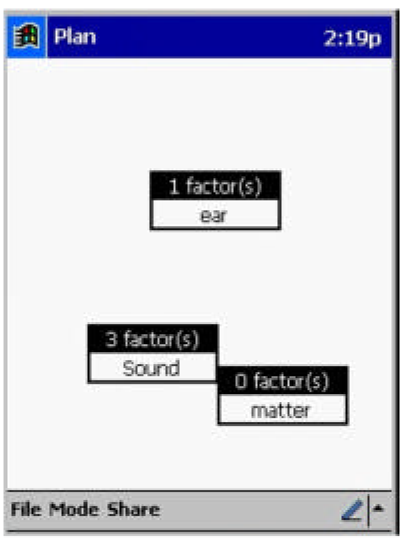


Figure 5: Pocket Model-It Plan

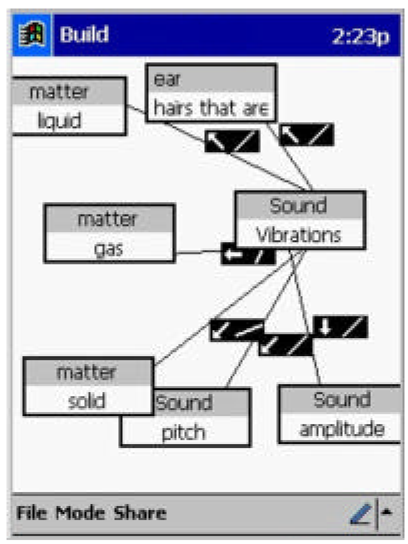


Figure 6: Pocket Model-It Build

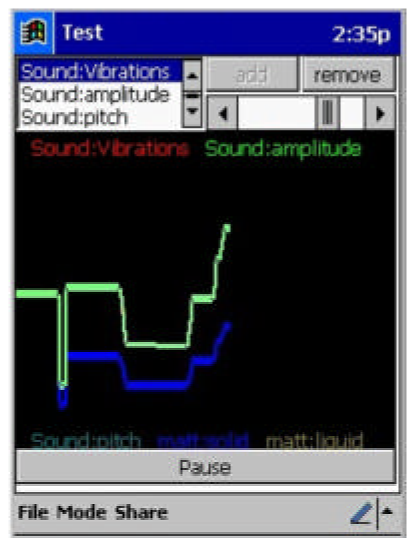


Figure 7: Pocket Model-It Test

Assessment Methods and Process

Pocket PiCoMap, ArtemisExpress and Pocket Model-It were used as part of a nine-month classroom study involving thirty-three students in two eighth grade science classes at a private school in Ann Arbor, Michigan. The primary data analyzed as part of the MaLTS project was gathered from eight focus students, two girls and two boys from each classroom. The assessment was conducted in two parts. First was an assessment of each scaffold to determine whether it was usable and whether using it actually supports learners. Six criteria adapted from LCD research with desktop software were used to assess each scaffold (Quintana, 2001; Quintana, Fretz, Krajcik, & Soloway, 2000). The first three look at whether students are able to find and use the scaffold:

- ***Accessibility*** measures whether or not students can find a scaffold
- ***Use*** is a measure of whether or not students use an accessible scaffold
- ***Efficiency*** measures how much difficulty students have when using the scaffold

The last three criteria for assessing individual scaffolds looks at whether using the scaffold assists students in engaging in the supported learning activity:

- ***Accuracy*** is a measure of whether the scaffold helps students complete the given task in an accurate and appropriate manner
- ***Progression*** assesses how students' use of the scaffold evolves over time
- ***Reflection*** measures whether the scaffold encourages students to reflect on their work

The second part of our assessment process looks at each handheld software tool as a whole. This assessment is important because students cannot benefit from handheld software that is difficult to use or to understand, even if the individual scaffolds are well designed. Four criteria were synthesized from LCD and UCD research to assess the overall handheld software. The first two criteria look at whether the constraints of handheld screens impact students' ability to use handheld tools to complete the supported task:

- ***Artifact Organization.*** This criterion assesses whether the constraints of handheld screens impact students' ability to organize their work. Desktop inquiry tools offer large screens for organizing work (e.g., arranging the components of a concept map) and often provide "persistent workspaces" (Kyza, Golan, Reiser, & Edelson, 2002) where students can collect and organize information over time. However, UCD research indicates that organizing work within small screens can be difficult (Lindholm, Keinonen, & Kiljander, 2003).

- ***Navigation.*** This criterion looks at how students navigate within individual workspaces and between different workspaces within handheld inquiry tools. UCD research with mobile tools highlights a number of potential navigational issues that may arise during the MaLTS study, such as difficulty navigating between pages in a web browser (Waterson, Landay, & Matthews, 2002) or difficulty scrolling (Buchanan et al., 2001).

The last two criteria look at whether the constraints of handheld computers impact students' ability to mindfully engage in the supported inquiry activity:

- ***Contextual Awareness.*** This criterion explores whether small screens impact students' awareness of the overall context of the inquiry activity. LCD research highlights the importance of providing visible process scaffolding to help students understand the component tasks and work processes involved with inquiry activities (Golan, Kyza, Reiser, & Edelson, 2002; Reiser et al., 2001). Yet there is little room within handheld software to make the overarching inquiry process visible to students, and the constraints of handheld screens limit how much of the learning activity students can see at one time. These constraints may make it more difficult for learners to understand the overarching inquiry processes.

- ***Information Transfer.*** This criterion looks at how students transfer information between different areas of the handheld tool. Information transfer tasks include physically moving information between different parts of the handheld tool (e.g., cutting and pasting text) as well as recalling and using information that is not currently visible. UCD research suggests that users often have difficulty with information transfer tasks when using mobile tools (Smordal, Gregory, & Langseth, 2002; Väänänen-Vainio-Mattila & Ruuska, 2000).

These criteria were used to assess how students used both individual scaffolds and overall handheld software during the classroom study. The next section provides an example of this assessment method and highlights some interesting results from the classroom study.

Example of Assessment Method

To illustrate the assessment of individual scaffolds, consider the previously described Link Scaffold in Pocket PiCoMap. The purpose of the Link Scaffold is to help students understand how the graphical links in their concept maps are interpreted in English. This is accomplished by providing an English description of the graphical links students create in their concept maps. Applying the previously described criteria to data about how students used the Link Scaffold during the classroom study gives the following results:

- **Accessibility:** High. The Link Scaffold was readily accessible onscreen.
- **Use:** High. Use was measured by whether or not student explicitly clicked on the Yes/No buttons in this scaffold. Given this measure, 7 of 8 students used the Link Scaffold in 14 of the 16 concept mapping activities (2 activities per student).
- **Efficiency:** High. None of the students had difficulty using the Link Scaffold.
- **Accuracy:** High. Accuracy was measured by whether students created links in the correct direction and labeled them with logical/correct linking words. Although 5 of the 8 students created a total of 9 links that were initially drawn in the wrong direction, all of these links were corrected by using the Link Scaffold to reverse the direction of the link. None of the final maps contained inaccurately drawn links, although the level of description or detail students used to label the relationship links in their maps varied.
- **Progression:** None. Students used the Link Scaffold as needed throughout the concept mapping activities; there was no clear change in students' pattern of use.
- **Reflection:** High. Reflection was measured by whether students actively confirmed the links they created (by clicking "yes" in the Link Scaffold) and whether they corrected links that were drawn incorrectly. During 8 of the 16 concept mapping activities, students explicitly confirmed links in their maps. Each of the 9 links that were initially drawn in the wrong direction were identified and corrected using the Link Scaffold.

Summarizing these results indicates that, overall, the Link Scaffold in Pocket PiCoMap was easy for students to use and successfully assisted students in understanding and interpreting the graphical links in their concept maps.

Pocket PiCoMap also provides a good illustration of the use of the first two criteria for assessing overall handheld software – Artifact Organization and Navigation. In Pocket PiCoMap, the primary organizational task was to arrange the concepts and links in the map so that the elements were readable (i.e., not overlapping or hidden) and so that the structure of the concept map conveyed students' understanding of the underlying connections between concepts in the domain. The results of the classroom study indicate that 4 of the 8 students had difficulty organizing their maps within the constraints of handheld screens. Figure 8 gives an example of a well-organized concept map, with the box indicating the limits of what could be seen within the handheld computer. Figure 9 is an example of a poorly organized map.

The primary navigational task in Pocket PiCoMap is to scroll (vertically and horizontally) to create and organize the concept map. Not surprisingly, the same 4 students who had difficulty organizing their maps did little or no scrolling. The other 4 students were able to scroll as needed and constructed well-organized concept maps.

Summarizing these two aspects of the Pocket PiCoMap assessment suggests that half of the students found it difficult to organize their concept maps and navigate within the constraints of handheld screens. However, students had no difficulty understanding the context of this activity or transferring information between different areas of the software. All of the students were able to create substantive (although sometimes poorly-organized) concept maps using this tool.

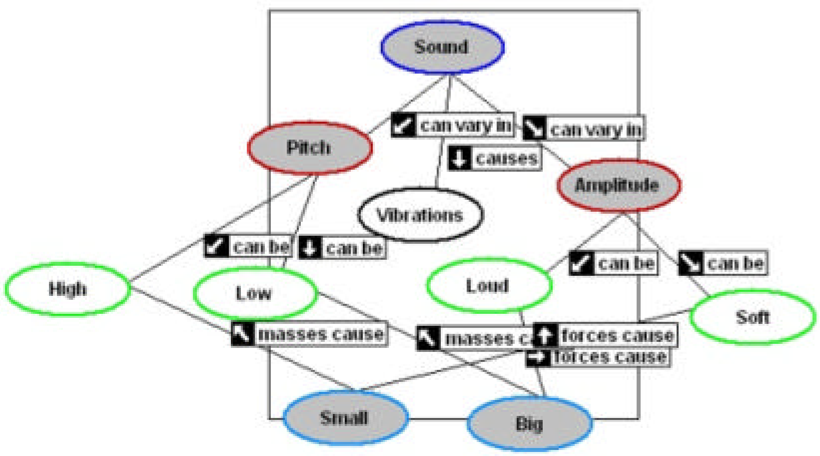


Figure 8: Well-Organized Map

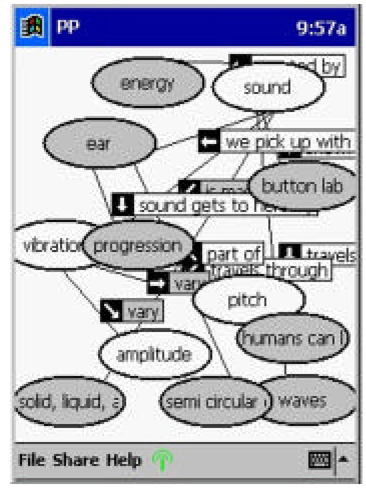


Figure 9: Poorly-Organized Map

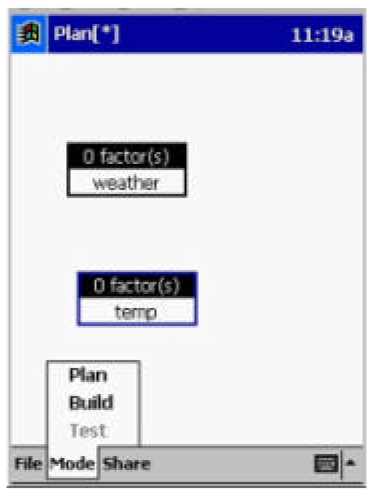


Figure 10: Pocket Model-It Plan mode, with "Mode Menu"

Pocket Model-It provides an example of how the constraints of handheld screens can impact students' contextual awareness. In Pocket Model-It, the modeling task is divided into three work modes (Plan, Build and Test). The overall modeling process is visible in the "Mode Menu" that is accessed at the bottom of the screen, as shown in Figure 10. The name of the currently displayed work mode is also shown at the top of the handheld screen. The results of the classroom study indicate that the "Mode Menu" did not provide enough process scaffolding for students to understand what they were supposed to do in each work mode. All of the students had substantial initial difficulty understanding which work mode was currently displayed (despite the fact that the name of the mode was visible onscreen) and what they were supposed to do in each work mode.

ArtemisExpress offers an example of how information transfer can be challenging for students using handheld software. The driving question folder in ArtemisExpress allows students to collect websites and notes that are relevant to their research activities. Students can save websites from within the “Site Description” area shown in Figure 11 by clicking on the button labeled “Save”. A link to the website is then automatically created in the active driving question folder; students can have multiple driving question folders but only one can be selected as the “active” folder for students’ current research activities.

In order to save a website to the correct driving question folder, students must remember which folder is currently active. This is an information transfer task because the name of the active driving question folder is not visible when students save a website. In 7 of the 31 activities with ArtemisExpress, students saved websites to the wrong driving question folders because they were not aware of which folder was currently active. Increasing the visibility of the active driving question by automatically displaying the driving question folder when students open ArtemisExpress did not have any apparent impact on students’ ability to recall which folder was active when they saved sites.

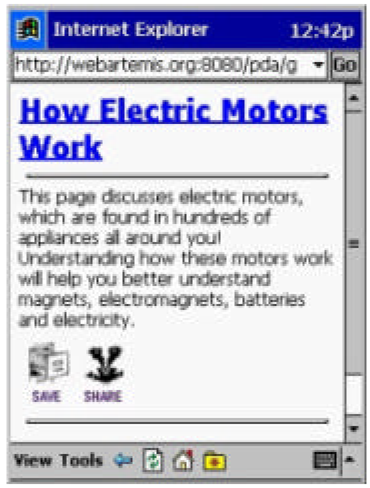


Figure 11: "Site Description" in ArtemisExpress

Summary and Future Work

The Mobile Learning Tools for Science (MaLTS) project is an effort to begin extending research in Learner-Centered Design to understand the challenges of building handheld software to support learners during science inquiry. Existing LCD techniques for assessing scaffolds in learner-centered software can be used to assess the design of scaffolds in handheld learning tools. However, the constraints of handheld computers raise new challenges when designing and using handheld software. To understand these challenges, we synthesize LCD and UCD research to identify four criteria for assessing the impact of small screens on the use of handheld learning tools: artifact organization, navigation, contextual awareness and information transfer.

Our future work includes an ongoing investigation of the benefits and limitations of handheld learning tools. While these devices are portable and flexible enough to support a range of learning activities, their physical constraints can make it difficult to support complex work. So, one challenge is to understand what types of tasks are too complex for handheld computers. Another challenge is to understand how to effectively combine handheld tools with other technologies, such as desktop computers, and how to use multiple handheld computers for collaborative activities.

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