“What I Want, Where I Want:” Reference Material Use in Tabletop Work

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ABSTRACT
Usable digital tabletop design hinges on a deep understanding of people’s natural work practices over traditional tables. We present an ethnographic study of engineering project teams that highlights the use of *reference material*—artifacts not the primary product or focus of work activity, but referred to or inspected while the work activity is carried out—in tabletop work. We show how the variety of reference material forms and their role in tabletop work suggest that digital tabletop systems must recognize external artifacts and should allow reconfiguration of external work surfaces and information.

Categories and Subject Descriptors
H.5.3 [**Group and Organization Interfaces**]: *Computer-supported cooperative work*.

General Terms
Design, Human Factors.

Keywords
Tabletop groupware, collaboration, reference material.

1. INTRODUCTION
Designing collaborative digital tabletop systems remains a difficult problem because we do not have a clear picture of the work activities that take place around tables [10]. To address this problem, we conducted an ethnographic study of three undergraduate engineering project teams, documenting their work activities in both the laboratory and meeting rooms from the inception to completion of their project over the course of five weeks. One of the key themes this study revealed was the remarkably frequent use of *reference material*—paper-based, electronically-based, and even tangible artifacts not the product of, but referred to in the course of tabletop work. Students used these reference materials upwards of 80% of the time, spanning a variety of form factors, and using them in a variety of tasks (programming, debating, copying or checking designs, etc). The significance of reference materials for our groups’ independent and collaborative work activity underscores two key design implications for digital surfaces:

1. Digital table input *must* recognize external artifacts.
2. Surfaces and information *should* be easily reconfigured and mobile.

Our work builds on the theoretical tabletop literature [10][11] by extending largely laboratory findings (e.g. [4][11]) with field observations of naturalistic work environments. We make primarily two contributions: first, we present a detailed account of reference material use, grounded in observations of collaborative work in a real-world table context, and second, we outline two design implications for digital work surfaces, framing them in the context of tabletop and physical paper research.

We set the stage by outlining two related areas of research: collaborative digital tabletop design, and studies exploring the process of paper use. We then describe our participants, their working contexts and the project course. This context frames our findings on reference materials, where we interleave our observations and analysis with actual episodes drawn from our sessions. This analysis motivates our implications for digital tabletop system design.

2. BACKGROUND: TABLES AND PAPER
Early investigations of tabletop activities focused on traditional table settings, emphasizing the importance of workspace activity [11] and the role of the medium [1] in the collaborative process. More recent work has revealed the important role of subtle orientation [3] and partitioning cues [9] in coordinating and managing the collaborative activity. Finally, Scott et al. [10] have suggested that tabletop systems should support external physical objects. We build on this idea by recognizing that reference material is semantically distinct from artifacts that are the focus of work activity, yet take on a variety of forms. *What role does reference material have in tabletop activity? How is reference material used?*

More generally, we know that collaborative groups use paper all the time—even in environments where technology is intended to supplant paper [5]. Luff et al. [5] attribute paper’s resilience to its tailorability, ecological flexibility and restrictions on personnel movement. O’Hara and Sellen [7] suggest that the paper reading process has benefits over online documents: paper better supports annotations, navigation, and provides flexible spatial layout. With regard to reference material, air traffic controllers constantly refer to paper strips as a form of concrete working memory [6]. In the context of research students, information retrieval from paper reference material produces four types of recorded information [8]: paraphrased information, verbatim copying, thoughts, and bibliographic references. This information is captured by annotations, note-taking, and photocopying [8], yet *how is*

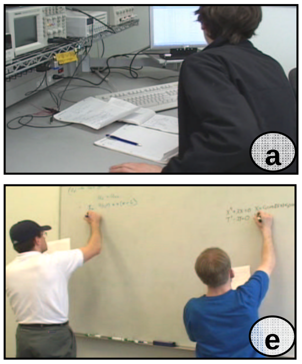
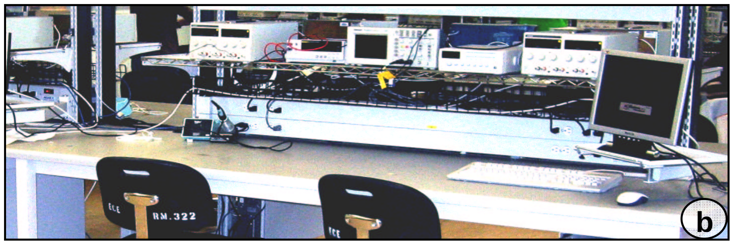


Figure 1. Clockwise from top left: (a) Larry referring to an LCD with his paper notes laid out; (b) the lab workbench; (c) Dean, the TA and teammate referring to the LCD—note the real workspace on the table in front of Dean; (d) Ivan soldering a circuit on top of his paper schematic, and (e) Ed and Anson whiteboarding and holding paper.

reference material used and captured in other working contexts? We became interested in the kinds of information contained in the reference material to understand how and why reference material is used in particular ways (e.g. on screen *vs.* on the table). This early work on the role of paper shaped our understanding of our own data.

3. CASE STUDY: ENGINEERING TEAMS

To understand the nature of tabletop activities, we conducted a five week field study of three undergraduate engineering project teams. This design allowed us to see behaviours and activities as they occurred in a traditional real-world setting; thus, although we observed only three teams, we observed them for over a month conducting real-world activities (as opposed to contrived tasks in a lab study setting) within the context of real world pressure. The teams of six were enrolled in a team learning program. In each five week module, teams are assigned a project (in this case, a magnetically-propelled train) with loose guidelines: teams independently design, test, and implement their project, and then present it, and submit a written report. Each week, teams are allotted three meeting room hours (with a table and whiteboard), and six hours in the lab (with a workbench and tools, Figure 1b). Groups regularly worked during these hours in allotted environments before going to other classes.

We observed and videotaped each team for at least one three hour block each week during the five week period (in total, 45 hours), and also observed unscheduled meeting room/lab time when the opportunity presented itself. Participants were told simply that we were interested in their use of tools in work activities. Participants moved in and out of the workplace, and variously arrived late or early; consequently, only two to four participants were generally visible from the camera at any given time (median: 3). To clarify activity, we interviewed participants when uncertain of what they had been doing.

3.1 Analysis and Findings

The frequent use of reference material emerged as a key theme. We found that reference material took a variety of forms, varied in how it was used, and finally, rarely had a single fixed location in the workspace, and was frequently moved. We took an iterative, grounded approach to analyzing our data, allowing coding categories and areas of interest to emerge as we watched the groups [3]. We triangulated our observations by fully transcribing two three hour periods with the video data. These two periods exemplified the general feel of the allotted working times: students completed tasks including paper-based design, materials work, and computer-based programming. During the transcribed working period, at least one participant in the video was visibly using reference materials 82% of the time (~4.5 out of 5.5 hours).

All groups followed a fairly similar trajectory: the first three weeks were spent prototyping the train using various materials, including designing and building the track, deciding the how the magnetic forces would work, building an inductor and programming the software/hardware interfaces. In the final two weeks, two teams iterated on their designs, optimizing for speed and efficiency, and the remaining team debugged their original prototype. Participants reported that about half of project work was done outside of the allotted times, so the lens of our analysis considers primarily their scheduled working times; however, it is reasonable to believe that our observations characterize the basic working processes even outside of scheduled working times.

3.1.1 Reference material is more than just paper

We had expected the students to use the lab time to simply *build* the component project pieces given the planning periods in the meeting rooms. Instead, as a part of their construction and design process, we saw *individuals and groups frequently studying and referring to various reference artifacts that included more than just paper.* For example, while the primary lab activity was the construction of project components (both electronic and digital), it was interspersed with periods of active learning and design. This hinged on the use of various reference materials including printed (e.g. circuit diagrams, problem sheets) and hand-written paper (e.g. formula sheets), tangible artifacts (e.g. existing circuit boards), and digital on-screen documents (e.g. schematics, data sheets). Figure 1a illustrates an example:

> *Larry is calculating the optimal number of coils the inductor should have. On his chair, he rolls to the LCD, swiveling it so he can see. Larry is looking up formulas on Wikipedia—he knows them, but forgets the details. Taking his existing "formula sheet," he copies these formulas down, and heads back to his work area. Larry places the formula sheet obliquely under his working sheet so that he can glance at the formula while working out the math problem.*

Larry uses two types of reference material here: the upright computer screen and his own formula sheet. Larry's visit to Wikipedia shows that information is not always brought into the work room in advance, showing the utility of non-linear, indexed online information [7]. As he copies the relevant formula from the page, he is paraphrasing the ideas by making notes [8], thereby creating new reference material for his own use.

Data sheets (for components) were also viewed frequently from the computer screen. Participants liked the ability to rapidly search online information: data sheets are often 50+ pages long, so finding one in a stack can be cumbersome. Also, since the majority of students did not have tools at home, most did their project work in the lab (which always has available computers).

> *Uta: "There's no point to printing [this webpage about Hall effect sensors] because I just need it for such a short period of time—I already know it, I just wanted a refresher."*
>
> *Carman: "It's so much easier just to look it up [online]. At home, I have a printed stack probably about six inches thick—just finding anything out of there is ridiculous, though."*

A handful of students preferred paper, citing the unreliability of the computer network, and the ability to learn things while commuting as primary reasons for printing data sheets. The form that reference materials take influence the way in which they can be used. For example, online materials can be easily searched; however, physical form factors are also useful:

> *Ian is copying a reference circuit design to his own breadboard. Ian holds the reference board and peeks underneath every once in a while. Ian puts down the reference board now, slightly out of the way, but easily within reach. He plugs the capacitors and transistors into his own board to match the reference design. Ian picks up the reference design six more times in the next 10 minutes, glancing at it even more frequently.*
>
> *Ian: "There's a [paper] schematic over there, but it's just easier to look at the real thing."*

Ian's episode with the reference board was similar to other individuals' experiences across the groups. To parallel prior observations with paper [8], Ian was simply copying verbatim using a form of note-taking. The tangible form factor allowed Ian to peer at different parts of the reference board—impossible with a schematic.

As illustrated, reference materials (e.g. paper, other artifacts) were often brought *into* the workspace, and set *on* the table where they aided the activity but were not the focus of the task (e.g. they are not work artifacts). Students placed reference materials so they were easily visible and within reach of their active working area, allowing them to rapidly view and manipulate the materials. Thus, to support the use of reference material, *digital table input* must *recognize external artifacts*, because users will often bring in and place external artifacts of various forms on the table. Disallowing physical artifacts from the table surface would hamper normal activity. Thus, these artifacts must not disrupt input mechanisms.

3.1.2 Roles of reference material

Our observations also revealed that reference materials play three roles in project activity: *pedagogical*—helping students learn and understand material; *communicative*—providing a context for discussion between group members; and, *authoritative*—providing factual information to inform activities. Latitude in these roles is facilitated by the *reconfigurability* and *mobility* of the reference material. For example, reconfigurable materials (such as the LCD monitors on moveable arms in Figure 1b) can be reoriented to engage others in discussion (e.g. [4]) by increasing visibility and easing reach. As illustrated in Figure 1c:

> *Dean is to build the most important piece of the project: the H-bridge. He has never built one, so he searches on the internet for H-bridge block diagrams. Later, he stares at the block diagram to understand how the various pieces interact and fit together. The lab teaching assistant (TA) sees that Dean has not moved for a while, and comes over. Dean turns the LCD so that the teaching assistant can see and reach it better (for gesturing). Together, they look try to understand the block diagram. Other teammates have gathered around the LCD as Dean and the TA work out the problem.*

Initially, the online document plays a *pedagogical* role, teaching Dean how the component works. The visibility of the LCD aids in the *communicative* role when the TA (who was not explicitly summoned) sees that Dean is having difficulty, grounding further conversation (e.g. [11]). The *reconfigurability* of the LCD screen facilitates the social process of team learning, similar to [7]. In contrast, a less visible reference book on the table would be less distinguishable from regular work (e.g. [10]), making it more difficult for others to see Dean's activities, thereby hindering the communicative role. Similarly, we saw information being transferred to whiteboards (from sheets of paper) when students were communicating to the entire team. The ability to quickly *move* information from a personal artifact (e.g. paper) to a public one (e.g. whiteboard) also facilitates the communicative role.

Figure 1d shows an intriguing example of the use of reference material in an *authoritative* role: here, Ivan uses a circuit schematic (printed on paper and laid out like a table mat) while constructing the physical circuit. Ivan follows the schematic like a plan, tracing the circuit paths before soldering identical paths on his circuit board. Of interest is that Ivan has lain out and is using his schematic in a way that parallels Larry's use of his formula sheet (Section 3.1.1): it is underneath his primary working area, but is clearly visible. The form factor again plays a role in how easy it is for Ivan to use the reference material: because the paper is thin and mobile, he is can simply place other materials atop, using it as a working area.

Traditional media offers users the flexibility to *reconfigure* the workspace [5]: users easily changed orientation of the LCD, transferred information from paper to whiteboard, and used paper in unorthodox locations. This flexibility allowed people to differentially convey information about their activities to others [10], and naïve attempts to provide reference material support by simply embedding it in the surface of the tabletop display would not fulfill all the various roles in the workspace. Instead, *working environments should facilitate easy reconfiguration of surfaces or at the very least, the movement of information between surfaces.*

Mobility of the reference material also appears to affect the role reference material plays: students often changed the *mobility* of the information (e.g. by printing a document or copying it) to effect particular coordination and collaborative styles. To explicate this concept, let us return to the episode with Ivan, who was soldering his circuit board based on a reference schematic (Section 3.1.2).

> *Dale has arrived, and looks to see what Ivan is doing. Dale asks if Ivan needs help. Ivan says no, but Dale stays anyway. Soon, Ivan has found something for Dale to do: Dale can hold the circuit board while Ivan solders. Ivan is "managing" the*

activity, and Dale follows Ivan's orders. After a while, Ivan does not understand the schematic, and eventually pulls the schematic out so Dale can look at it.

The implied immobility of reference material (in this case the schematic) coordinates the activity: since only Ivan can see the schematic, he retains primary control of the activity. By making it accessible to Dale later, the reference material becomes communicative, it enlarges Dale's role. Similarly, the current setup of the workbench, with the LCD on a swinging arm (Figure 1b), makes the LCD mobile (compared to a fixed position). This mobility allowed Dean to swivel the LCD into a compromise position, allowing the TA to help (Section 3.1.2). Importantly, these LCD repositioning episodes occurred fairly frequently, allowing the students to quickly look up authoritative information online while retaining their existing workspaces.

Mobile reference material allowed students to move when table space became a premium. Larry copying formulas from the online document to his own formula sheet is a good example of this concept (Section 3.1.1). Figure 1e illustrates another example:

Ed and Anson are going to work on the math problems, but first, Anson prints out two copies of the problem sets. Later, they work at the whiteboard, each with a problem set in hand. The problem set is a reference sheet: they copy down the problem, and begin work. Neither puts it down. They refer to it every once in a while when they get stuck. Anson says this is to check if he copied the problem correctly, and to see if there is anything that may be useful.

By printing, Anson moved the information to a form factor that was more mobile, allowing him and Stan to work in their preferred environment. In our sessions, students moved reference materials around frequently (e.g. [5]): this flexibility helps coordinate activity in a communicative role (as with Dale), and also facilitates preferred working arrangements by supporting easier reach and visual access. Thus, tabletop system designers should ensure *surfaces and information are easily reconfigured and mobile*.

4. DISCUSSION & CONCLUSIONS

Our findings have two clear implications for the design of tabletop environments to support reference material use: first, designers of input technologies *must* recognize the presence of external objects, and second, workspace surfaces and information should be reconfigurable and mobile. We have seen heavy reliance on physical reference materials for both independent and group work on tables. Because these materials are often placed on the tabletop, input technologies *must not* be confused by these objects. An added difficulty is that people often *rest* on the table itself, yet a resting elbow or arm is typically not intended as input. We understand this presents a difficult engineering problem; however, to support real-world activity, input technologies for digital tables must recognize the role of external reference material. Second, we believe that reachability, visibility, and mobility of reference materials have a large impact on the roles they can play (particularly the collaborative role). Allowing users to flexibly place and move objects about the physical workspace allows them to dictate the prominence of certain aspects of objects as appropriate to facilitate certain communicative roles. Although in its infancy, PaperWindows is a nice approach that allows digital documents to be moved about with some of the flexibility of physical paper [2]. Yet, even a simple approach such as placing display surfaces on a reconfigurable arm (Figure 1b) provides many of the benefits of mobility.

We have provided an account of the nature and use of reference material by engineering project teams, outlining their various form factors, the roles they play in collaborative and independent work, and the importance of reference material mobility. *Are these findings constrained to only this particular context?* Because our teams were composed of non-expert students, we likely saw an over-representation of reference material use (because they were still learning)—other types of teams would likely not use reference materials quite as much; however, we believe strongly that the *manner* in which reference material is used would not differ. Furthermore, tabletop work is typically embedded in the larger context of collaborative work [10]; consequently, designers should expect external materials to be frequently brought to the tabletop. We believe careful attention to this aspect of tabletop use will help designers create better tabletop systems to support collaborative work.

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