Breaking the Book: Translating the Chemistry Lab Book into a Pervasive Computing Lab Environment

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ABSTRACT
The UK e-Science programme is relying on the evolution of the paper lab book into a pervasive data gathering lab system. To date take up of existing commercial or research lab book replacement systems has not been great. In this paper, we reconsider both the role of the lab book in the experimental cycle, as well as its affective and experiential properties as an artefact, in order to design an e-Science lab book that will be acceptable to the scientists who will use it. To this end we combined and extended existing design analysis models in order to assess the artefact functionally and experientially. We present the approach we developed, the prototype we designed based on our analysis, and the results of the formative study we performed of the artefact in real use. We show that our design elicitation method strongly contributed to the success of our prototype's take up.

Author Keywords
Design methods, e-Science, pervasive computing

ACM Classification Keywords
H.5.2 Information Interfaces and Presentation: User Interfaces – evaluation/methodology, prototyping, user-centered design

INTRODUCTION
The e-Science community is deeply involved in developing services to support both shared computation and shared information in 21st Century science [9]. As part of this development, the community is keen to convert laboratories to pervasive computing environments, where data generated in the lab can be captured and published automatically; where information generated can be combined and compared with other labs on demand [17], and where provenance can be readily discovered [16]. One of the challenges in this move to digital data sharing in Chemistry is the paper-based lab book. The lab book is the *de facto* standard for recording experiments. Both commercial [20, 6, 21] and research efforts [1, 4, 18] propose ways to digitize the book's data. Adoption of such systems, however, has not been great. Demonstrating successful take up of research prototypes has not been the focus of published papers. Take up of commercial systems in the e-Science community, however, has also been small. Indeed, a representative quotation from interviews with chemists about experience with two such eLab book systems was "We wouldn't touch those with a barge pole. They're horrible… Not for us." That these systems capture the data required to go into a lab book is not a question on the part of the scientists we interviewed. That scientists have such a visceral response to them suggests that there are qualities to the lab book-as-artefact that have not been captured effectively by these systems, either functionally or affectively. There is, therefore, a need to elicit and incorporate these attributes in designs in order to produce systems scientists will accept.

CHI 2004, April 24–29, 2004, Vienna, Austria.

The Lab Book-as-Artefact
In this paper, we present the studies we carried out both of the lab environment and of the recording process performed during an experiment in order to elicit the functional and experiential qualities of the lab book. We review the prototype we developed and show how we evaluated it in real use. In particular, we present an innovative method we developed to address problems we found with applying field studies techniques in this domain. The method, Making Tea, facilitated both the design team's observation and understanding of a domain practice where we are not experts; it also helped experts translate both their practice and their artefacts for the team in terms with which we could engage. The results from our combined methods helped us to design a digital lab book that affords the functional and experiential qualities of a paper-based one, while transparently introducing additional benefits for lab practice available in a digital system. We present the results of the study, and propose the findings derived from this analysis as bench marks for designing digital lab books for pervasive e-Science labs.

RELATED WORK

Lab Books

The electronic lab book space can be charted between two axes: the degree to which paper is kept/replicated or entirely replaced on one axis, and the degree to which the system for the device is personal (like a lab book) or distributed (like the web) (Figure 1).

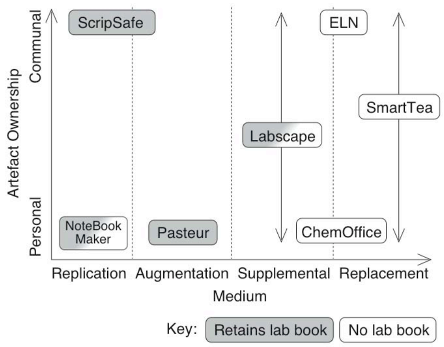


Figure 1. Lab Book Space. Smart Tea represents our project.

Replication. Commercial systems like SCRIP-SAFE [21] are largely deployed to strengthen intellectual property (IP) claims. Custom lab book pages are created for each lab and include user identification. The scientist creates annotations on the pages similar to regular lab book entries. The pages are then scanned. Searches can then be run to retrieve the experiments, but the scientists' annotations themselves are not converted into searchable form.

Supplement. The Labscape Lab Assistant supports experiment planning and data entry. The scientist creates a plan for an experiment by arranging icons representing lab processes into a graph of the experiment. Throughout the lab identical stations are available which display this graph. The scientist clicks on the appropriate part of the graph, which enters a dialogue box for data entry. This system does not claim to replace the lab book. Indeed, published papers show that the lab book is still in use, and that printouts of the graphs are taped into books where hand written entries are visible.

Replacement. ELN [18], ChemOffice [6] and NotebookMaker [20] provide desktop applications that present paper form-like interfaces for entering experimental data. These tools for the most part, take the scientist out of the lab, and therefore implicitly assume that either there is a PC available to the scientist in the lab, or that the scientist is making recordings in a book in the lab and then redoing them, using these applications, at the desktop, so that the digital results can be shared, or so that the data can be recast into effective visualizations for analysis and paper publication.

Augmentation. a-Book [4] provides devices which literally augment paper-based lab books. These augmentations, such as attaching a lab book to a tablet, or providing a PDA to act as an annotation lens over a lab book page, attempt to allow the scientist to continue to use the familiar lab book while adding additional devices to this book to enable digitization of new input. While feedback seemed positive, there was also an awareness that there was a certain cumbersomeness to the prototypes and that the additional effort to add metadata to the captured information for search and archival purposes was not always perceived as a plus.

Of the above systems, only a-Book [4] considers the particular affordances of the lab book as opposed to what scientists do or record *while in the lab*. The analysis, however, is largely centered on the qualities of paper that it assumes would be difficult to replicate with non-paper-based interactions. This assumption is not proven. Further, the acknowledged cumbersomeness of their augmentation devices motivated us to investigate alternative approaches. While the Labscape work seemingly presents the most complete digital model of an experiment, the paper lab book is still shown to be part of the cycle. We therefore decided to start from scratch in our consideration of the lab book to see how we could design a completely digital system that would be experienced like a lab book, but whre the data could be ubiquitously available, as per the e-Science agenda. Our hypothesis was that discovering and integrating affective attributes with their functional counterparts would improve take up of a system.

Design Methodology

To investigate the functional requirements of the system we needed a mix of approaches that would let us look at the role of the lab book–as-artefact, its context of use, and the process of recording events in the book. Since take-up by chemists is paramount, our approach was fundamentally user-centered**.** We ran pre-design interviews with chemists and visited their lab space both to continue discussions *in situ*, and to carry out ethnographic observations [1] of the ebb and flow of work in an analytical chemistry lab. We would later use task analysis [10] of their interactions with the paper-based lab book during an experiment to model the functional requirements for the services we developed. Before we could get to the task analysis, we needed to understand the relation between the experimental and the recording processes. To assess that, we first needed to understand the experimental process.

Ethnography yielded the larger context of interactions in the experimental environment. This helped us appreciate the context of the lab book-as-artefact within the dynamic nature of the lab. Interviews gave us a sense of the culture, the rationale for what chemists do, and who the stakeholders are in the lab book life cyle. We describe these findings in the next section. Neither of these approaches, however, gave us sufficient insight into the *what* of the practice such that we could build a model of the process to discover either (a) what of the recording practice itself could be translated into digital support services or (b) what the important experiential attributes of the artefact were that should also be translated from the analog to the digital. We had two main problems in this: time and domain knowledge. The length of time of real experiments (days, weeks, months, years) made real-time observation of an experiment from beginning to end largely impractical with limited resources for field work. Likewise, given all the time in the world, the practices being observed lacked significance as non-experts, since we did not know what was happening, nor could we assess whether we were observing "good" or "bad" practice, either with respect to the experiment itself, or in the chemist's recording of it.

Extant design methods were not helpful. Scenario-based design [5] and activity theory [19] focus on illuminating the context and structure of an (understood) interaction rather than the experiential effect of the interaction with a given artefact. Story telling [15] with its emphasis on building detailed narratives of specific characters and environments captures the feel of the environment and relevance of the practices in which the processes to be modeled take place. Story telling, however, depends on these processes already being understood well enough to be translated into a rich narrative. Artifact walk-throughs [2] are designed to help get at this why of a practice, but the technique assumes that both interviewer and participant share an understanding of the artefacts used and the task performed.

Where there is little or no domain expertise in the design team, on-site one-off apprenticeships and/or mockups [23] have the team involved in hands on training either on the actual site (apprenticeship), or in a controlled environment (mockups). These techniques gives the design team an excellent feel for the task they are modeling, and in that respect, captures the experiential nature of the process as well. The literature in this space suggests, however, that the approach has mainly been used in contexts of specific repetitive tasks where the team can be trained to perform the task in a relatively short period of time. It is not clear how well this technique could be applied to more loosely structured, context dependent tasks like analytic chemistry that also require a high degree of domain knowledge.

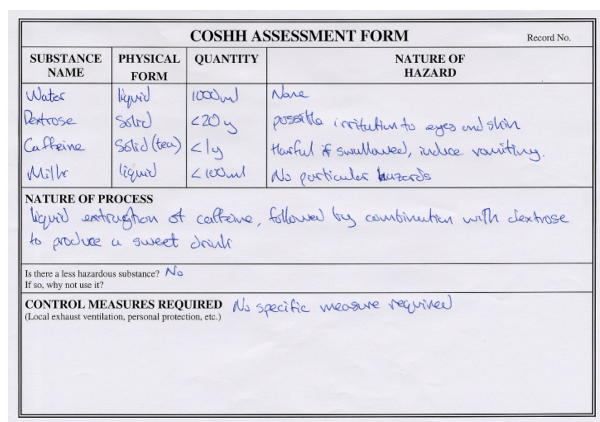
The closest technique we found to interrogate process, practice and artefact experientially was Dix's "Deconstruction/ Reconstruction" of Christmas Crackers [12] (crackers are a British party favour). Dix describes methods to investigate both the cracker's physical and experiential/affective attributes in order to translate these qualities into a digital representation of a Christmas Cracker. While Dix's model proved effective, the approach implicitly assumes that the design team is already expert in the functional properties and the cultural practices and experiences associated with the artefact. With the exception of one member of our group, this was not the case for us. We needed to develop a bridging approach that would (a) compress the complete experiment process into an observable time scale and (b) use terms we could understand and interrogate for design analysis. The method we developed is called Making Tea, design/elicitation by analogy. We describe it in the following section.

DESIGN APPROACH: UNPACKING THE BOOK

Making Tea is designed to be used in concert with field studies and other methods such as task analysis. Indeed, in order to achieve our goal of understanding both artefact and its lifecycle, we used all of these techniques. We describe our field study findings first, then the Making Tea method and its results. We then review the resulting prototypes.

Pre and Post Lab Use of the Lab Book

The lab book is used to record the experiment alone. Use of the lab book is framed by the preliminary experimental plan and post experiment analysis. In the planning/approval stage, chemists in the UK are legally required to fill out a COSHH form (Figure 2). In this form, the chemist states what chemicals will be used, the procedures that will be followed, and most particularly, what hazards, if any, are associated with the chemicals themselves or the processes being considered. The form is filed and signed by an approving body – usually a lab manager or supervisor. The form serves several purposes. Primarily, it acts as a device to have chemists make explicit to themselves any risks involved with what they are doing. The secondary role, however, is the requirement to articulate a (safe) plan for the experiment. The COSHH's requirement to make a plan explicit was introduced in 1988 [22] apparently to much resistance. It is now taken as a fact of experimental life.


COSHH ASSESSMENT FORM Record No.

SUBSTANCE NAME	PHYSICAL FORM	QUANTITY	NATURE OF HAZARD
Water	liquid	1000ml	None
Dextrose	Solid	<20g	possible irritation to eyes and skin
Caffeine	Solid (tea)	<1g	Harmful if swallowed, induce vomiting.
Milk	liquid	<100ml	No particular hazards

NATURE OF PROCESS liquid extraction of caffeine, followed by combination with dextrose to produce a sweet drink

Is there a less hazardous substance? No
If so, why not use it?

CONTROL MEASURES REQUIRED No specific measure required
(Local exhaust ventilation, personal protection, etc.)

Figure 2. COSHH Form, showing the hazards of making tea.

After the experiment is complete, the chemist, outside the lab, will write up – usually at a computer – the analysis for the experiments performed. Part of the motivation for the digital lab book service is to make available in digital form the material collected in the lab experiment(s) related to a given published result. At present, the chemist must re-enter this data and chase up local references to previous related experiments to include in these documents.

Context of Use

There is one lab book per researcher. As a collection of both current and previous experiments, the lab book travels with the researcher on site, both within the lab itself, and to meetings of a project team or to meetings with a supervisor.

Within the lab, the book will likely be moved several times in the process of carrying out an experiment. Indeed, something we observed in our site visits, and something most of the chemists commented on, is that there is no real room for the lab book while running an experiment: it must be squeezed into whatever space is available, and is, consequently, not always in the best location to support recording of results. For instance, most chemistry experiments take place within the confines of a fume cupboard (Figure 3). This area is equivalent to a stove in a kitchen, and as such is a hostile space for paper. The usual location for the lab book is what is referred to as "the bench." The bench is a multipurpose area: it is used for preparation of materials that will be processed in the fume cupboard; it also holds anything not in the fume cupboard, from additional chemicals to be measured, to used glassware (Figure 4). The chemist will find a place to situate a lab book, and will move back and forth between the fume cupboard, the bench and various other areas of the lab, such as the scales, supply cupboards and analysis mechanisms. At each of these moves, some event takes place – the measuring of a chemical, testing the degree of completion of a process – usually requiring the chemist to record either a value or an observation into the lab book.

Figure 3. A fume cupboard in a chemist's laboratory. Inset, the distance between the fume cupboard and the bench.

In some labs, this may mean that because of the distance between the fume cupboard to the bench, the chemist is either making trips back and forth between event location and recording location, or is literally holding a lab book under one arm while performing a reaction. In the lab where we did our trials, the bench was opposite the fume cupboard (Figure 3, inset) so for the most part, the chemist would walk across to the bench, and need to face away from the reaction being described in order to face the area where the book is situated.

Physical Affordances

The chemistry lab is a hostile environment for most materials in it. When asking a chemist what the best material might be to put in front of an electronic screen for its protection, the reply was "a brick." Part of the success of the lab book has been its resilience in these environments: a bound lab book can be stuck in a corner or balanced on a shelf without fear of breaking it. It is not, however, invulnerable to data corruption, as the inset of Figure 4 shows. One can, however, readily flip back through previous work; it is a usable size for both sketching and annotating sketches. Chemists sketch often: they will draw out the apparatus for a dangerous or uncommon experiment; they illustrate the molecules that result from a reaction; and they draw the results of purification tests.

Figure 4. The bench area, with paper lab book open, (lower right, circled). Inset shows lab book entry damaged by spill.

UNDERSTANDING THE EXPERIMENT: MAKING TEA

Before we went forward with making tea as an experiment, we validated our analogy with senior domain experts. Their approval gave us confidence in the soundness of our approach; it also gave other members of the project an understanding of what we were trying to do and how we were trying to do it. Similarly, Making Tea as an approach gave us the means to engage chemists in terms we could understand, while also problematizing the "natural" experimental process for the chemist. The expert had to think about and articulate where the experimental process did and did not correspond to the analog of making tea. We learned as much from where actual experiments fell outside the analogy as from where they matched. This result is not surprising. Analogy is a well-established pedagogic method to support learning [6]. Practically, Making Tea helped maximize the effectiveness of our time available for field studies: it let us translate what we were only partially able to observe in the chemistry lab into an analogous but complete, observable and interrogatable process in our design space. Indeed, our technique let us run the making tea experiments several times in various forms. Initially we used only kitchen utensils to familiarize ourselves with the experimental and recording approach (Figure 5, left). The next time, we used lab equipment. This helped familiarize us with the chemical apparatus and the constraints a chemist may have working with digital recording devices in the environment (Figure 5, right).

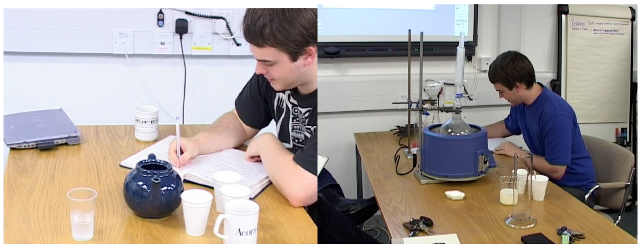


Figure 5. Team chemist making tea as an experiment with domestic equipment, left, then with lab apparatus, right.

In terms of interrogation, Making Tea let us ask meaningful questions of both the experimental process and the recording practice at a level that would not necessarily have been possible if we had watched a "real" experiment where we would not have the domain expertise to engage the process. In other words, a chemist in an expert walk through could tell us "we now add acetyl chloride to Benzene to perform a Friedel-Crafts Acylation," and we would all nod our heads. With tea, we could ask whether or not it really *is* important, in terms of the experimental process, to add the milk to the cup before the tea or vice versa. Similarly, the tea analog let us question what an experiment is designed to capture. For instance, we learned that making a cup of tea is actually two experiments. Making the tea is one complete experiment. Making a cup of tea – using the tea "compound" from the first experiment and adding milk to it – is a second experiment. Thus, the description of an experiment as "something to create a single complete reaction" becomes meaningful: make tea, then make cup of tea. Several differences between tea and tea-as-chemistry emerged: in a lab, the tea compound is not all used immediately: it would be stored in a freezer for an indefinite period, and cups of tea made from that same batch of compound. Similarly, if some of the tea got spilled on the bench, the bench would be scraped and the wood scrapings put through chemical processes to reclaim the tea. Nothing can be wasted, since the cost of generating a compound can be high, both in materials and time.

We similarly learned that seemingly precious little of what happens in the lab is actually recorded. Our sped up process made this even more apparent than looking at actual lab book entries for experiments that had taken weeks to run. Indeed, the main questions we asked during our tea runs were "When do you record that [whatever was just done]?" or, "Why didn't you write that down?" In the description of the tea experiment, we expected to see notes about the apparatus, the brand of tea, and why decanting (rather than filtration) was used. All that was recorded were the amounts used, the times tested and the amount of tea that resulted (Figure 6). We learned that chemists, like computer programmers writing code, tend to under-document a process. Chemists, similarly, have a known corpus of specific procedures to rely upon: to say the tea was refluxed is generally sufficient to cue an understanding of a rich process where the specific method of reflux is often left unspecified. Thus, the lab book captures surprisingly little of the detail of the experiment, as can be seen in the chemist's notes from our tea experiments.

This is not to say that, as with code, more documentation would not be better, but we learned multiple factors can impact what a chemist records. For instance, data like best before date on the tea or its brand do not get recorded, not because the information about the batch may not prove important – a bad batch rather than a bad process may result in the success, failure or non-repeatability of a process – but because the inventory system may not provide that level of detail for a chemist to record. We also learned that due to the length of time an experiment can run, chemists will likely have several experiments in play at once, thus having to manage recording for multiple processes concurrently.

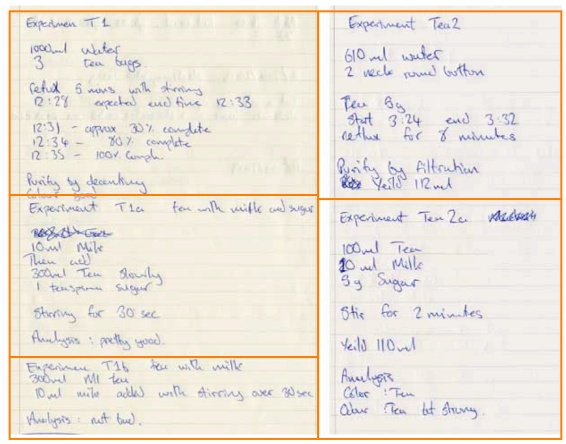


Figure 6. Lab book entries for 5 experiments: T1, tea, T1a A cup of tea with sugar, T1b a cup of tea with milk and sugar (left); Tea2 tea; Tea2a, cup of tea with milk and sugar.

Beyond Process

Our discussions with the chemists though Making Tea often became punctuated with descriptions of cultural practices as rationalizations for recording practice. These observations flowed far more readily in the context of running the tea experiment than they had when interviewing the chemists directly about their use of lab books. From these mid-tea exchanges we formed a compelling picture of how the lab book's multifaceted roles overlap: the lab book acts as both a recording device for communal science and as a personal journal. As a journal, it is a personal object, and treated as such. While there is a recognizable form to an experiment, entries are idiosyncratic. Also, while its data is a communal resource, the object is not: one does not go poking through someone else's lab book uninvited. The uniqueness-value of its data also means that the book is protected by its author/owner. It is rare to hear of a lab book being lost. It is also a legal record of what was done when. The physical/temporal aspect of the lab book itself reinforces the date of a record on an experiment: this individual book was used during this and only this period. As such the book has a near-totemic status: intellectual property claims are often founded on the presentation of particular lab book entries and their dates as evidence. There is also a potential aura to the book as a part of history, especially with the lab books of now-great scientists – there is a sense of unmediated realness and immediacy of the scientists' actual moments of discovery, unavailable in the polished, published result.

DIGITAL ARTEFACT DESIGN: BREAKING THE BOOK

In our design, we wanted to capture the positive experiential attributes of the paper-based lab book while reducing the weaknesses of current practice. We wanted to do this without changing the chemists' practice in such a way that the perceived cost to use the system outweighed the perceived benefit. The affordances of the book we wanted to translate to the digital were: ease of access for flipping between previous and concurrent experiments; simple data entry for measures, free form sketches and annotations; portability in the lab, and secure data storage. We also wanted to maintain the experience for chemists that they could record as little as possible and expend minimal effort in the lab to capture the experiment.

We created several lo-fi prototypes and ran design reviews with 6 chemists by running our tea making experiment with the prototypes. We used the results from these sessions to create a hi-fi prototype that we again reviewed with the chemists. In the end, the closest actual element of the design that bore a resemblance to the book was the hardware platform: we used a wireless tablet PC. The tablet could be carried and placed like a lab book. It also supported free form input with a stylus; its design has been shown to be appropriate for these kinds of annotations [14]. In other respects, our translation to the digital broke the book-ness of the artefact: rather than emulating the book in which all parts of the experiment are written linearly down the page, we deployed four, randomly accessible services: dry measures, liquid measures, bench and storage service. The data for these services was initially populated by entries from a modified COSHH form. The regular COSHH form includes the chemicals, their planned amounts, hazards and process to be used for the experiment. We expanded the process section, requesting the chemists to itemize the anticipated steps that would be carried out. The data collected from the form was then made available to the appropriate lab book services, immediately eliminating the chemists' need to recopy data from the form to their lab books, which is current practice. Adding detailed steps to the COSHH process meant that, once in the lab, scientists would only need to annotate a step if the actual step varied from the planned step.

From our discussions in making tea, for instance, we learned that while a chemist plans to use a certain amount of a chemical, the actual amount used will differ. Our dry measure service, therefore, took the planned measures from the COSHH and provided a field beside each named chemical where the chemist simply tapped in the actual amount used and hit "enter" to confirm and store the amount (Figure 7, left). As we also saw in making tea, while measurements are rigorously recorded, what of the process is annotated varries. In the bench service, therefore, the process steps from the enhanced COSHH were represented as a list. Tapping on a step in the list opened an annotation field where chemists could write or draw comments about the step if they wished (Figure 7, right and Figure 8). In the bench service, we emulated the immediate "save" affordance of writing notes on paper: annotations were saved as soon as they were entered. A check box beside each step, and a status bar also show at a glance how many steps were complete, and which were outstanding.

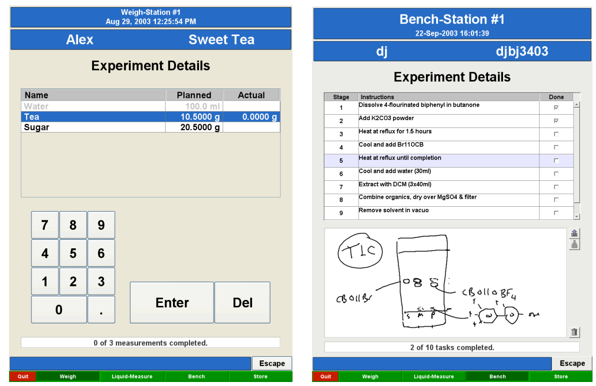


Figure 7. The measuring component, left; the Bench component, right. The bench shows typical drawing annotations (in this case a TLC purification) by chemists.

Instead of flipping or scrolling through virtual pages to access past information or record notes in concurrently running experiments, chemists click a tab at the base of the screen directly to the appropriate service associated with the particular kind of information sought (dry measure, liquid measure, processes). With respect to data security and intellectual property, we transparently time stamped each entry as it was made, and copied each entry as it was made over the network to the server. Here the system took care of a back up chore automatically that the chemists, in practice found cumbersome to manage – and so frequently did not – yet know is an important practice. While our design broke with the metaphor of paper-base book, our services, we hoped, replicated the positive experience of the book and transparently improved some of its weaknesses.

EVALUATION METHODOLOGY

A successful lab book implementation is not about reducing the time it takes to run an experiment since these times are fixed by the time a chemical reaction takes. It is not about reducing the number of steps taken in the lab since this is also largely fixed by the physically distributed layout of lab apparatus. In a case where take-up will be a critical factor for the success of a considerable part of the e-Science agenda, predicting whether a design will be used is a potentially more compelling first evaluative criteria than counting steps taken to perform a process with or without the device [8] especially when such a measure may not have an overall bearing on *use*. As Dix states, "If a system is not *used* it is *useless*" [13]. We therefore used Andrew Dillon's evaluative model of *Process, Outcome, Affect (POA)* [11] as a good predictor of whether or not an artefact may be *used*. In POA, the question would be first about process: were the chemists able to do what they wanted to do – use the system to record an experiment. Second, was the outcome from the process what they expected: the experiment was recorded in a useful/meaningful way. Third, did they feel "positively affected," "empowered" by their use of the system, such that the perceived benefit outweighed perceived cost.

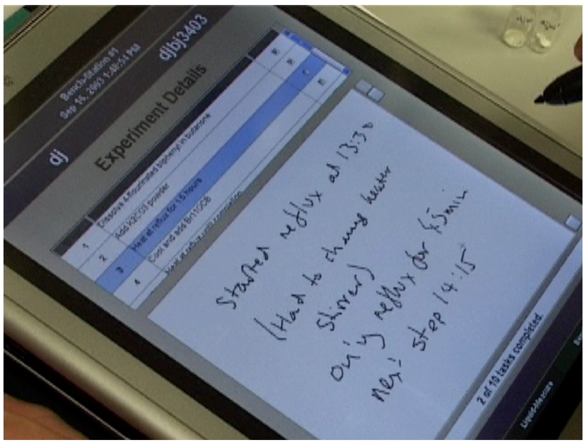


Figure 8. A chemist entering a note into the digital lab book.

We ran a formative study against the POA criteria to observe how real chemists interacted with the system in place of their lab books to record real experiments in all the messiness of a real lab environment: with many experiments taking place in the lab concurrently and multiple chemists sharing lab space and resources. *Our benchmark for success was that within ten minutes of first time use, the system would "go transparent:" the chemists would be able to focus on their work and simply use the system as they would a lab book.* Three chemists participated in the study over the period of a week. One chemist carried out two experiments; the others, one each for a total of four experiments. We were lucky to have this number of participants, as we were taking time away from their work to spend engaged in the evaluation.

OBSERVATIONS AND INTERVIEWS

Process. The chemists were all able to carry out the recording activities of their experiments. No chemist had to make an additional entry on paper that the lab book could not support. Initially the chemists treated the system quite gingerly, but after a few minutes into their experiment, they started to treat it as they do their lab books: placing it on a bench, consulting it for their next step, and using it to make an entry. They tabbed easily between components for data entry. Chemists frequently moved between making annotations for a step in the experiment and measuring out a chemical in a list. Occasionally a chemist would return to a previous experiment in the middle of entering a measure in order to make a note that had been forgotten earlier.

Outcome. Each chemist described the main positive feature of the system as the security they felt knowing that the data entered into the tablet was being written immediately to a server, so that if something happened to their "lab book," the data would not be lost: "I can go anywhere and its, like, this is me and my data. It's all there! Bang!" The other chemists echoed this sentiment. They also commented on enjoying the "neatness" of the layout of the steps. They noted that they would not usually be so detailed in writing up their plans for an experiment, but that the benefit of an "extra ten minutes work" was worth it. Similarly they reported on occasionally documenting more than they usually would if they were using just their lab book. They provided many UI refinement suggestions, but none that fundamentally changed the UI design of the system.

Positive affect. Beyond being pleased with being able to record their experiments transparently, the chemists expressed enthusiasm for the vision driving the prototpye. As one chemist put it, "I liked the concepts and ideas behind the whole thing, as in the whole pervasive nature of the data. The whole fact that what you can capture in more detail, and so consequently its kind of like its a step towards it [a pervasive lab]… I'd rather be in the position we are aiming towards rather than the position we are in now."

ANALYSIS

The chemists were pleased overall with the system. We met our test goal in that the tablet became transparent to the experimental process within ten minutes of actual use. This suggests that we captured the artefact functionally and experientially. The chemists' desire to adopt the system reinforced this. Their experience of the system also went beyond direct use: their perception of the pervasiveness of the system that their data was both *safe* and *available* to them "anywhere" addressed concerns about the of analog lab book's vulnerabilities. The system also promised to keep doing more to help them do their work. The chemists know we have been building services to replace chores they do in planning experiments, like looking up the chemical hazard information and molecular formulae, and performing mole value calculations. "That's where we spend so much time: looking stuff up… those [services] will be so useful." While our digital artefact passed our used/useful test, it was also experienced as more than just the artefact we gave them, even though several of the features they lauded (such as mole conversion of measures) had yet to be incorporated into the prototype they used.

CONCLUSIONS AND FUTURE WORK

In this paper we present our approach to addressing the lab book replacement problem by combining traditional user-centered design techniques with more novel approaches to capture both functional and experiential properties of an artefact. Our contribution to design methodology has been Making Tea – affect and expertise elicitation/translation through analogy. Making Tea gave us both common ground and time. It gave us as researchers and designers familiar ground through which we could engage in questions about practice and affect around an artefact that may otherwise have gone uninvestigated without the analog to help make them apparent. Likewise, casting experimental practice into kitchen terms problematized a normal practice for the domain experts, helping them articulate their practice through elaborating where our analog broke down. Most particularly, Making Tea gave us time: it made a process that could stretch beyond the practicality or effectiveness of field studies, manageable and repeatable. We can see the use of this technique for modeling processes and artefacts in other complex activities with large time scales. For instance, a contractor managing a building project that could take several months to several years might be difficult to observe effectively via field methods alone. Building a dollhouse from scratch might be an appropriate analogy for both compressing and translating the process. We will continue to explore the generalization of the methodology for interrogating high-duration, loosely structured, expertise-rich, complex processes.

The result of our combined approach is a tested, *used* artefact. As such, we have confidence to build on the prototype as a foundation for a pervasive lab book platform. For instance, we wish to explore if we can break the book paradigm further and deploy lab book services at appropriate sites in the lab, rather than having them all on one device. From this work, we plan to develop a method for determining the cost/benefits for deployment/take up of communal vs. personal devices in pervasive environments.

ACKNOWLEDGMENTS

This work (www.smarttea.org) is part of Comb*e*Chem (EPSRC GR/R67729/01). We thank HP and Kirk Martinez for the Tablet, and David De Roure, Alex Rogers, Wendy Hall and especially Alan Dix for their input and support.

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