Making Tea: Iterative Design Through Analogy

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ABSTRACT
The success of translating an analog or manual practice into a digital interactive system may depend on how well that translation captures not only the functional what and how aspects of the practice, but the why of the process as well. Addressing these attributes is particularly challenging when there is a gap in expertise between the design team and the domain to be modeled. In this paper, we describe Making Tea, a design method foregrounding the use of analogy to bridge the gap between design team knowledge and domain expertise. Making Tea complements more traditional user-centered design approaches such as ethnography and task analysis. In this paper, we situate our work with respect to other related design methods such as Cultural Probes and Artifact Walkthroughs. We describe the process by which we develop, validate and use analogy in order to maximize expert contact time in observation, interviews, design reviews and evaluation. We contextualize the method in a discussion of its use in a project we ran to replace a paper-based synthetic chemistry lab book with an interactive system for use in a pervasive lab environment.

Categories and Subject Descriptors
H.5.2 Information Interfaces and Presentation: User Interfaces – evaluation/methodology, prototyping, user-centered design

General Terms
Design, Human Factors.

Keywords
Design elicitation, pervasive systems, design methods, tea, chemistry, eScience

1. INTRODUCTION
This paper is about Making Tea (MT): design elicitation through analogy. Making Tea is particularly suited to design elicitation of practices that are loosely structured, can last over a long period (days to years), and are highly expert in nature. Making Tea is used as a complement to other user-centered design methods, such as field studies and task analysis.

In Making Tea, the design team and the domain experts collaborate on constructing an analogue of the actual process to be modeled. The analogue remains true to the process while using simpler analogous components. The use of the analogue has three main benefits: (1) it allows the team and experts to step through the complete process in a tractable time, (2) it provides a way for the design team to interrogate a practice that is otherwise beyond their expertise to interpret and (3) the analogy helps domain experts articulate where the analogue breaks down, thus making it easier in some sense to describe the practice through a kind of contrast/comparison between analogue and actuality.

Another benefit of the Making Tea approach is that it is a socializing force in the design process. The analogue acts as a *lingua franca* between designers and domain experts, which among other benefits, helps keep communication channels during the design process open.

In the following sections, we describe the motivation for the development of the Making Tea method; we look at how Making Tea relates to other design elicitation approaches, and we describe in detail the Making Tea approach in the context of a case study: designing a digital lab book for synthetic chemistry. We conclude with our observations for carrying the method forward.

1.1 Motivation
We developed Making Tea to help us understand a physical practice – the use of a lab book in recording experiments in a synthetic chemistry environment – in order to translate that practice into a digital system (Figure 1).

Figure 1. Making tea with the Smart Tea digital lab book system: testing in the design space and in the lab (inset).

The paper-based lab book is the fundamental record of a science experiment. It is a robust mechanism that allows for multiple kinds of gesture capture, from text to graphics to

objects pasted between its covers. It has been used successfully for hundreds of years in multiple science domains, and is used regularly to support intellectual property claims. Its media, however, makes the distribution of its stored contents difficult. In an evolving paradigm in UK science, referred to as eScience, there is an objective to get all data generated around an experiment available for sharing across networks and services enabled by the Semantic Grid [7]. In part, this goal means developing approaches to capture data digitally that has formerly either not been captured at all (like ambient temperatures in a lab during an experiment), or has been captured only on paper (like the observations of a process during an experiment). There have been other efforts to design lab book systems for chemists, but to our knowledge, none of them have enabled complete replacement of the paper lab book so that all aspects of the recording process to be captured digitally. Furthermore, take up of these systems in the synthetic chemistry lab has not been great (see [20] for a review of these systems). Our mandate was to design a system that could replace the paper book with a digital solution.

In order to undertake this design, we wanted to understand the lab book-as-artefact both in terms of its socio-cultural as well as functional rolls. We therefore began our investigation using a series of user-centered design methods: interviews with the stakeholders, ethnographic observations of the chemists performing experiments in their labs, post observation interviews. A more detailed discussion of this process is reported in [20]. While the observations and interviews gave us a solid understanding of the environmental, cultural and legal rolls of the lab book, we also needed to model the functional process of how data is entered into the lab book. Task analysis would seem a natural approach. But task analysis we discovered has a set of implicit assumptions: that the task can be observed, and that the task can be understood well enough by the designers to create a sensible model. We found that we could not immediately apply task analysis to this problem because of the nature of the process to be modeled itself: we quickly learned that experiments are loosely structured, highly expert and duration intense: experiments can last from days to years, taking observation of a complete experiment beyond the limits of our budget; experiments are dynamic: the knowledge required to respond to a particular situation requires a high degree of experience and expertise. Indeed, in an initial effort to map the task action/recording processes, when asking chemists "is that what you always do at this stage" the answer invariably came back "that depends."

We soon realized that we did not understand what we were seeing well enough either to model it effectively or consequently to design an appropriate interaction. So we made tea. Through a process of discussion with chemists we learned that our making tea is an analogue for synthetic chemistry experiments. This was a Eureka moment: since we understood tea, we had something we could work with. We all shared making tea as a common expertise. A chemist could make tea, as an experiment. By replacing making some unfamiliar chemical compound with the analog of making the very familiar cup of tea, we were able to focus on our design interests, the experimental recording process. We could observe, ask questions, and begin through this elicitation, to pull together our other studies and begin to design.

Making Tea also proved a powerful tool for expert elicitation, making it easy for a domain expert to say when the analog was accurate and where it broke down. As we describe below, it also enhanced the other methods we used, such as ethnography and made task analysis possible. While these more traditional methods gave us rich information about the what and how of the chemists' environment and practice, making tea gave us a way of getting at the why (and why not) of that practice. Being able to get at the why of the process improved our understanding of the experiential aspects of the artefact and the practices involved with the artefact. It also gave us a way to regularly validate our design assumptions against what we came to refer to as the Tea Model. We could readily consult domain experts using our tea *lingua franca* to ask questions about real practice to see if our design ideas were making correct assumptions about lab practice.

2. RELATED WORK

Making Tea is a complementary method for user-centered design approaches like ethnography [2], task analysis [8] or scenario-based [4] design. In our use of analogy to situate and explain practice, Making Tea is also informed by Bødker *et al.*'s participatory design's concept of the positive effect of creating a common design language between designers and the domain experts [3]**.** The use of analogy – in this case, making tea as an experiment – may be seen as a kind of participatory design informed mock up of the system to be built. While, as we describe below, we do use mockups specifically in our meetings with chemists to gain thoughts and feedback about proposed designs, the analogy, in this case Making Tea, has a different primary intent. First, the use of analogy, of making tea as an experiment, is not a mockup of a proposed system design; it is instead a method for gaining insights from design experts about their practice. Second, in this respect, the intent of making tea is distinct from participatory design's goals, as for instance exemplified in the UTOPIA project. In that case, as both Clement and Van den Besselaar [5] and Spinuzzi [23] suggest, the focus was to "democratize" the workplace, from workers on the floor through levels of management. Part of the goal was political: to change the way technology was introduced into workers' lives by enabling their participation in the design process. Building mockups formed part of the discourse practice of workers learning how to design.

In contrast, our primary use of analogy has not been to teach the defined user group (in this case chemists) how to design; rather, we used analogy *primarily* to inform *our* perception of and understanding of the process we would ultimately develop into mockups for design review. As we describe throughout this paper, the model of making tea had persistent value throughout the design process beyond this initial for us learning about a specific process: it was a common point of reference between designers and chemists. Making Tea became a shared neutral space. Rather than chemists coming to design world or designers interloping into chemist world, Making Tea became a place for a possibly different kind of exchange among stakeholders and designers (further thoughts on these kinds of design territories can be found in [21]).

Primarily, Making Tea, more than an atefact design method, is a design elicitation method. Its chief distinction from other elicitation methods is around expertise and task duration. Well-known design elicitation methods like artifact walk-throughs or story telling implicitly assume that the expertise for a task is translatable, and the time to observe a task is tractable. Making tea was developed specifically to address the issue of domain expertise, where the tools or techniques to be

modeled by the designers are unfamiliar to the design team, and would require specialized, potentially extensive training, to become domain savvy.

In order to situate Making Tea in the context of design elicitation methods, we look at the following range of approaches: cultural probes, story telling, apprenticeships, artifact walk-throughs and deconstructing experience. .

2.1 Cultural Probes

First presented by Bill Gaver in 1999, [14] Gaver's probes were used to elicit experiential qualities of life in various elderly communities in the Netherlands. The probe pack contained various recording materials to elicit reflection, including, for instance, postcards pre-addressed back to specific researchers with requests to reflect on particular questions. As Gaver explains, the probes were used less to map a one-to-one correlation between any of the items explored and any digital artefact the design team would create, and more to inform the design ideas Gaver's team of artists already had. In 2002, Hemmings *et al*. redeployed cultural probes with a stronger focus on gaining insight into how the probes might be used to solicit information that could directly assist the design of systems to support in home care for the elderly [16].

In each case, there was a desire to explore the design space as sensitively and as unobtrusively as possible. There was also a need to develop tools that could be used at a distance. By having the participants build up a collection of multimedia reflections that could be mailed back to the researchers, the probes kept their distance while supporting personalized reflection. As Gaver describes them, they are like space probes that get sent out and can start trickling back information over time.

In our case, we had a far more concrete notion of the specific artefact we were translating from the physical to the digital, and therefore could engage more directly with the scientists about its use – there was less concern about how direct interrogation might violate the chemists' space, though there was equal interest in getting at the story of the book in use.

2.2 Story Telling

Story telling is a method frequently used for communicating concepts between design and developer teams which may be involved in a project [15]. It is largely an after-the-fact method. That is, after the information from other observation and analysis techniques has been processed, the results are converted into a story. Story telling goes beyond scenarios. The stories involve the development of a rich narrative including well fleshed-out specific characters rather than generalized stereotypes. The idea of story telling is to communicate the attributes of a design context in terms of the specifics of use and the specifics of an environment of use. Developing such a rich story takes experience and narrative skills in order to catch the richness of the experience and requirements. It may be seen as a stronger tool than scenario-based design [4] because it deals with the specifics of an actual design situation.

In our case, if we had to communicate our findings from our combined observation methods to another design team, we might very well work with a writer to translate these into a rich story that could form the basis of our design efforts. Developing that story, however, is informed by other methods, such as observation, interviews, task analysis (or making tea). It represents a synthesis of what the design team finds critical to communicate about the context of use, and the function of the tool itself. Indeed, when giving talks about this research, we frame the motivation for our work with a light weight version of story telling: we tell the story of the Chemist doing an Experiment in order to communicate to a lay audience the complexity, hazards and challenges of the environment and how their current tools and work practices fit into that environment.

2.3 Apprenticeship and Mock Ups

Some researchers in the industrial design space have looked at going on site to become an apprentice to a domain expert literally to get the feel of the given practice they have been asked to design [22]. Similarly, design teams work with the domain experts to produce mock-ups of a process and then have the team members perform the experts' tasks, under expert supervision, to complete the process. The goal in each case is to give the design team a sense of hands on experience to help the team members understand the process empathetically and experientially.

This technique is obviously useful when considering the real-world context for a design's deployment, when the position of a lever, for instance, could have gross consequences in the physical workflow of an environment. It is also a useful reality check for a designer's assumptions about an environment. It is also potentially a complement for GOMS-like predictive modeling of a procedure, which may not take into account the physical effects of a design decision.

In our case, we were focusing on replacing a tool with which every member of the team was already familiar: a paper-based lab book. Indeed, each member of the team uses a lab book just about every day, though increasingly the laptop computer is replacing its prevalence. As such, the relevance of an apprenticeship for direct hands-on experience for performing an experiment was not germane to what we were trying to model: we were not trying to automate the experimental process; we were attempting to understand the rational behind decisions to record particular events in a lab book and seemingly ignore others. This rationale is something we could better get by engaging a chemist directly while observing the experimental process. A type of mock up, however, is critical to the making tea process, and we describe this in the Making Tea section below.

2.4 Artifact Walk-throughs/Models

Similar to protocol analysis where participants think aloud while using a new piece of software to complete a task, artifact walk-throughs or artifact models [1] are a think-aloud protocol to structure field observations around the use of usually non-technological artifacts. The think-aloud is used to walk the interviewer through the process of completing a task. These walk-throughs can help the interviewer infer possible design intent by asking probing questions about why one thing was done rather than another, such as, for instance why a message was written onto a post-it note, rather than into a log book.

Artifact walkthroughs were designed as part of "customer-centered design." Most of the examples in the artifact walk-through/artifact model work refer to artifacts that are generally shared in common with the interviewers for carrying out familiar practices such as making appointments or taking notes, or searching for information in the process of carrying out work-specific tasks. The technique does not take into consideration what happens when that shared understanding

of artifacts is not present. In the chemistry lab book experiment, but for the lab book, both the technology used and the process for its use were unfamiliar to all but one member of the design team. While the lab book itself was familiar to all, the recording process was not. As such, a non-domain expert would not find an artifact walk-throughs helpful.

2.5 Deconstructing Experience

The closest analog to Making Tea is Dix's Deconstructing Experience – pulling crackers apart [10]. Indeed, Making Tea is an extension of the Deconstructing Experience technique, specifically designed for non-domain experts.

In "Deconstructing Experience," Dix's team analyzed both the physical and experiential/affective attributes of a Christmas Cracker, a party favor given out in the UK at Christmas time. The cracker is a tube wrapped in tissue containing an assortment of toys like a paper hat, a prize like a puzzle, and a terrible joke. The cracker is opened by one person pulling on one end of the cracker, and another on the other. Frequently, the cracker goes off with a bang (like a gun blank). Almost as often, the cracker goes off more with a whimper, but this is part of the experience: will it or won't it pop and singe someone's hair. Dix's goal was to find a way to capture and translate these qualities into a digital representation of a Christmas cracker. The team worked out both the physical (colorful, includes toys, has sound) as well as the experiential (delay, surprise, must include another to pull apart) attributes. From these, the team worked on how to translate these effects from the physical to the digital.

While Dix's model proved effective [11], the approach implicitly assumes that the design team is already expert in the cultural practices and experiences associated with the artifact to be translated. With the exception of one member of our design group, this was not the case for us. Therefore we needed to develop a bridging approach that would allow us to elicit practice *and* affective experience from the chemists in a way that we could likewise analyze and incorporate into our translation of the physical lab book to the digital system. This became Making Tea.

3. MAKING TEA

Making Tea is a multi-stage process based on the concept of learning by analogy [12]**.** Analogy is usually used to help introduce new concepts through a discussion of known concepts [6]. Students may be introduced to the concept of atoms first as analogous to a raisin pudding. More properties of atoms can be introduced by a comparison to the solar system, with particular emphasis on orbits of planets around the sun. Each stage of the developing analogy reflects the leveraging of previous understanding to support new understanding: both in terms of how the new model is like the previous model, as well as how the new model is unlike the previous model.

Making Tea was developed particularly to address the gap between design team knowledge and the domain expertise required for the interaction process to be modeled. In our case, we wanted to understand the synthetic chemist's experimental process. In particular, we wanted to understand the chemists recording process physically – in terms of what activities took place where in the lab that required recording, from measuring chemicals to mixing compounds – and abstractly, in terms of what *specifically* they recorded about an event, how they recorded it during an experiment (drawing, notes, references) as well as why they recorded these particulars rather than others. While field studies and task analysis would help us understand the context of use and the functional process of performing a recording task, most of us on the team felt that such observations left us at a remove in understanding sufficiently the real-time decisions being made in carrying out an experiment, and deciding what to record. This would also leave us less able to engage the chemists effectively about their practice. We come back to this point in section 3.1 below.

One option would be for us to enroll in a first year chemistry course, but we neither had the time for this, nor the need to become chemists, since we were more interested in the role of the recording process in an experiment than in the experiment itself. We also did not want to become "experts" per se, and possibly miss certain assumptions in a practice that an expert may not question or express. We therefore needed a technique that would get us closer to that process, so that we could both appreciate the subtleties of what we would observe, and engage in conversations with chemists at a high enough level that we could make the most constructive use of their valuable time – and ours. Our previous experience, for instance, working with complex expert systems for engine design had suggested that expert walk-throughs of processes were not the most efficient way to address the kind of problem we faced. Experts can get passionate about explaining low-level detail that, while important for their work, does not necessarily effectively illuminate the core issues of the process to be modeled.

The analogy of Making Tea as an experiment would potentially provide us with the leverage we sought for understanding the attributes of the process we wanted to translate from the physical to the digital, provide a mechanism for experts to communicate with us in a focused and productive way for the goal to hand, and to maximize contact time both observing and engaging with the experts.

Making Tea evolved as a multi-stage process that we used through out the design cycle. The stages are

- Defining an appropriate analog
- Validating the analog with domain experts
- using the analog to interrogate practice
- using the analog to test translation of practice from the physical to the digital. (This last stage of translation is an iterative one, where design revisions are checked against the model repeatedly.)

In the rest of this section, we go through each stage of the process in turn. In the sections following, we look at how we evaluated our approach, and then at how the approach integrated with the other user-centered methods we used.

3.1 Determining the Analogy

We hypothesize that the strength of the technique is in the quality of the analogy, as assessed along three factors in particular: how familiar the design team and domain experts are with the analogy; how well the analogy can help the design team focus on the process/artifact to be modeled; how well the analogy can be mapped onto the actual process.

In our case, we needed a method that would allow us to focus on the process of the experiment rather than on the particulars of various chemical combinations. It needed to be sophisticated enough to reflect a sufficient number of the

properties of a regular experiment to be meaningful, and to allow for realistic recording practice throughout the experiment.

We initially proposed two candidate analogs: making a martini and making tea. Making Tea was chosen for several reasons. While some of the team members had an affinity for martini making, all of the team (made up of UK and Canadian nationals) were keenly familiar with making tea. Tea also had other benefits. First, the equipment for making tea was readily to hand. Second, according to our team expert, making tea leant itself to experimental refinement for follow up experiments, in which making tea is one experiment, and making various kinds of cups of tea (with milk, with sugar, with both) are distinct experiments making use of the original tea "compound." Before we had even begun we were learning about the nature of an experiment: to make a compound, and to use that compound in discrete experiments adding new compounds to it.

3.2 Validating the Analogy

Making tea was to be used as an analog for making any chemical compound such as aspirin or naphthalene. Making Tea would let us replicate the *process* of an experiment. It would let us focus on that process rather than on the chemicals being combined, because we understood how to make tea or a cup of tea as well as a professional chemist knows how to make acetylsalicylic acid.

Our first validation of the Making Tea analogy came from our software design team member, seconded to our design project. He had worked as a research chemist, and so was invaluable to our team. We return to this point in section 6 below. While we felt confident of the strength of our making tea analogy for our focus on process, we wanted to make sure that this analog would be equally recognized as valid among domain experts beyond the team. We presented the analog at a meeting of professional chemists involved with our project. The analog was well received. Indeed, the chemists present each contributed further reasons why tea was an appropriate analogy for the synthetic chemists' process. Indeed, one of the chemists suggested that likewise, the synthetic chemists' experimental practice was a good analog for other chemists' practice. Thus, making tea would give us synthetic chemists that would be a solid analogy for other chemists, such as combinatorial chemists.

It was after presenting this analogy to the chemists in the project that we leaned our analogy had further resonances within the chemistry community: we started to receive email of articles of making tea in the history of chemistry, starting with George Orwell and running up to the British Standards Organization with a tangential feud between chemists and physicists about the proper way to make a cup of tea – including the chemical effect of adding milk first or after the tea has been poured (see smarttea.org).

While not critical to the development of an appropriate analogy, the added value of this resonance within the community of both an appropriate and historically apposite analogy, beyond having a method to let us interrogate a process effectively, had the added benefit of inducing an enthusiastic response from the domain experts with whom we discussed the project.

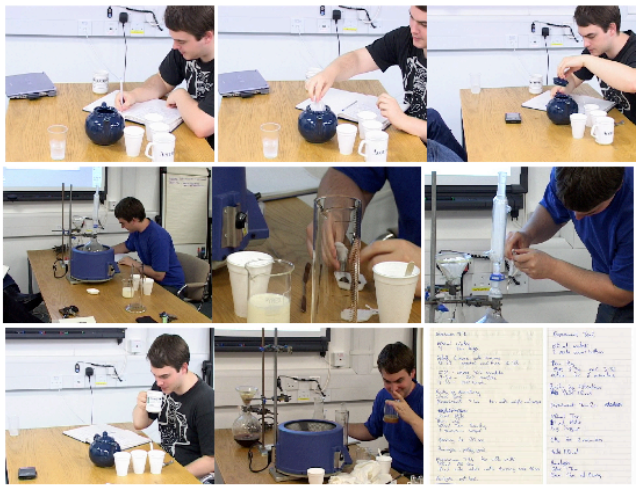

Figure 2: Top row. Making a pot of tea and two cups of tea as three distinct experiments, using regular tea-making apparatus. Second row, making tea and two cups of tea (one with milk, one with milk and sugar) using appropriate synthetic chemistry apparatus. Third row, comparing the results in each case. The write-up of each experiment is shown in the last cell (see Figure 3 for larger view).

3.3 Using the Analogy to Interrogate Practice

Once we had defined the analogy and validated it, we iterated two versions of running making tea as an experiment. First, we ran Tea with regular kitchen utensils. Second, we ran it with proper chemistry apparatus. The approach here is similar to mock-ups, except that our purpose was not for the design team to get the hang of running an experiment, but for the design team to get comfortable with the experimental process, gaining familiarity and knowledge with each version.

3.3.1 The Kitchen Version of Tea

The first iteration of making tea as an experiment was to make a pot of tea and then two cups of tea, one with milk, the other with milk and sugar, using regular tea-making utensils. (Figure 2, top row). Our team chemist took us through each stage of the experiment, from formally measuring the tea (2 bags) to testing the tea (by color and scent) for completion of the reaction. While the most simple, this version of the tea making experiment gave us the best opportunity for expert elicitation in terms of how making tea is actually different from an actual experiment. We learned that, unlike tea, chemicals can "steep" for hours or days, and unlike tea, steeping for longer than necessary does not usually matter, whereas with a pot of tea, tea bags left overly long produces a potentially unpalatable beverage. This comparison had an immediate impact on one design idea, which had been to prioritize putting a stopwatch into our digital lab book for reaction checks. We also learned that nothing could be wasted. While we would mop up spilled tea from a table, the chemist would scrape up every bit and then go through however many processes required to recover the tea from a lap coat or a tabletop.

In this respect of focusing on the differences between our analogy and the real thing, we were moving in an opposite direction from the use of metaphor, for instance, in the GUI world, where the goal is to use a metaphor to introduce a new system. The problems for user's mental models of a system

when metaphors break down, however (a word processor is not a type writer) are well known [13]. Rather than using an analogy to hide the differences, we were able to use it to elicit differences in ways constructive to the design process.

For instance, in tea, there is an ongoing debate about whether to add the milk to a cup before or after the tea has been poured into it (see smarttea.org for a list of papers on this question). Because of our knowledge of tea, we were able to pose the question: is the order in which you pour chemicals into a vessel to make a new compound important? This is not a question that we would have been able to ask if we had simply been observing an expert walk through of a regular experiment. If a chemist had said "I add compound X and then chemical Y" we would have noted first they add the compound, then the chemical. This may have lead to a design decision to constrain ordering in the presentation of the items in the lab UI as the chemist works through their experiment as presented to them in the application. It turns out that ordering, unlike in tea, does not matter. Similarly, we were able to ask questions about what was recorded during the process – or, more frequently, what was not recorded during the process. Because we were familiar with the tea process, we were less concerned about interrupting our chemist to ask questions while he carried out the experiment. We knew where the risks were. If this had been an actual experiment, we would have been less confident in interrupting an action for risk of damaging a sensitive process. True, we could have gone through the videotape after with the chemist to say, "why did you do that?" as with post experiment interviews. But the real-time exchange both saved time since we did not all need to go through the video again, and maintained the immediacy of the context, allowing for a more dynamic exchange.

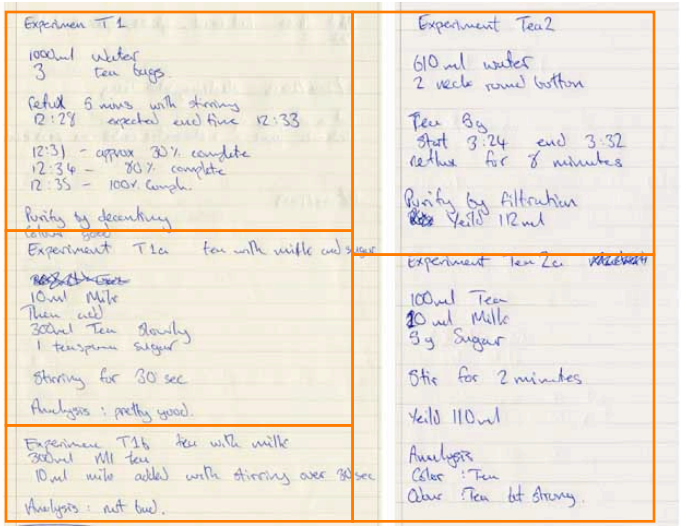

Figure 3. Each square contains the right up of a complete experiment, for 5 experiments in all. Page 1 represents the three tea experiments made with kitchen utensils (Make tea, make cup of tea with milk, make cup of tea with sugar and milk). Page 2 represents the two experiments run with chemistry equipment (Make Tea, make cup of tea with milk and sugar).

3.3.2 Making Tea with Chemical Apparatus

The next iteration of the experiment was to make tea with real chemical apparatus. Making Tea this way gave us the opportunity to get a better feel for the environment in which an experiment is carried out. New questions arose from this version, such as, what happens when something goes wrong? In this case the filter paper for decanting the tea got clogged. More particularly, how would this problem be recorded? Or would it? Does only the positive result get recorded? The exposure to unfamiliar apparatus still in the comfortable context of tea let us focus on new aspects of the experiment from the kitchen version, which lead to more comparative discussions on purification methods and testing for "doneness."

One of the critical facts we learned from making tea in this instance was more of a similarity than a difference between the tea analogy and an actual experiment: just as a good cup of tea cannot be rushed (it takes time for the tea to brew), likewise, it takes the time it takes for a reaction to occur. In other words, the success of our translation of the physical lab book to the digital would not be measurable in helping the chemist take less time to run or even record an experiment. In the process of an experiment, there are stages of sometimes acute activity, and potentially even longer stages of watching the pot steep, as it were. This simple insight gave us an early indicator of the challenge we would face in evaluating our prototype, since efficiency in terms of number of steps taken or saved would not necessarily be a meaningful measure of effective design.

Figure 4. Making tea with many chemists in simulated lab environment. Upper left shows team chemist moving between simulated bench (right) and weigh scale/fume cupboard area (left). Upper right shows chemist with prototype lab book UI (in white square). As the chemist operates the mock up UI, the visiting chemist (lower right) can see the actions with the UI on the screen (lower left).

One of our observations in both iterations of making tea had been how little was recorded in each experiment. Figure 3 shows the entries for 5 complete experiments on 2 pages of the lab book. As we describe in section 4, this paucity of detail is consistent with regular experimental write ups. We learned there are several reasons for this: one is that chemists have a rich body of shared knowledge about a process, so that to say something was "refluxed" is sufficient to queue up an entire process. As one of the chemists we interviewed later said, however "that doesn't tell you how hard it is to do." That said, much is not captured that could be, that would be useful to know. If a batch of tea tastes awful one might check the best before date on the box for the tea. If an experiment goes awry,

currently it is difficult to trace it back to the chemical because that batch information may not be available to the chemist, and thus is certainly not recorded. This inspired us to develop a service to integrate with the chemistry lab's inventory system with our digital lab book services. This service would automatically record batch information of chemicals used in an experiment, the information available on demand [17].

The kinds of questions, observations and proposals described above arose because of our probing the actual unfamiliar experimental process through the analogy. We focused as much on difference as on similarity. Indeed, just as making tea helped us understand the experimental process through familiar terms, the dissimilarity between making tea and running an actual experiment helped the domain expert articulate attributes through difference. Being able to say "a real experiment is different from this in the following ways" helped our domain expert explain attributes of the process that otherwise may have gone without comment had the analogy not been there to elicit these comparison breakdowns.

3.4 Using the Analogy to Test Prototypes

Our final, formal stage of making tea was after we had prepared two versions of a lo-fi [19] lab book prototype. For this run, we invited in four additional chemists to get their feedback on the designs we had produced. We used our analogy to facilitate a design review with the experts.

We simulated their lab environment in our Demo Room. Our team chemist demonstrated how they would interact with the digital lab book while running an experiment (figure 4). As the chemist walked through the experiment, the state of the UI was projected on the large screen so that the chemists could see what would be happening with the UI. Again, by making tea, rather than trying to carry out an actual experiment, which would itself require more attention to detail, we could focus on the process of interacting with the digital book during an experiment. As well, we could focus on soliciting the chemists' comments on the recording models we were demonstrating.

We knew that we had a strong model when the chemists would say "it would be nice if it could do X" and we could show that it already did X with respect to recording at different stages in an experiment. We learned when chemists really would like a camera to be taking pictures for occasional reference back to a state of an experiment that they may have missed during one of those phases of intense activity. Again, because we were using tea, we were all able to focus on the process rather than detail of a particular chemical reaction. This helped both to solicit comment on the design and encourage exploration of services not currently available but that would be useful – such as on the fly calculation of molecular weights for chemicals and their gram equivalents as chemicals are being measured: chemists prepare these values manually in advance. Once they get to the scales, the actual weights change, throwing out their pre-planned ratios, which must be recalculated. An automatic service calculator would save time in initiating an experiment, if not in running it.

In this last iteration we combined our analogy with a design review that allowed for a very natural interaction with the participants. In this case, making tea as an experiment helped the visiting chemists feel grounded in their observations about the prototype – they could point to familiar artifacts in making their observations without getting caught up in the specificity of a particular experiment's details. The analog helped all of us focus on the design and questions about the design through a common reference.

4. INTEGRATING TEA

As stated above, Making Tea was developed as a method to help us bridge the gap between domain experts and design experts. It helped us leverage our observations and facilitated our interview process with chemists. In this section we describe how making tea was interleaved with these other techniques.

4.1 Enhancing Ethnography

Figure 5. The lab the area on the left side is the fume cupboard, where chemicals, frequently hazardous, are mixed. The area on the right is the bench, where everything from used glassware to one's lab book fight for space.

We introduced Making Tea after our team had done an initial observation of a synthetic chemistry lab in action and initial interviews with the chemists in the group to understand their level of interest in replacing their physical lab books with digital versions. This first contact alerted us to the rich, multifaceted complexity of their environment (Figure 5 and 6) It also gave us our first live confirmation of what our literature review regarding the success of previous lab book initiatives had been. This reinforced our sense that a fundamental design requirement would be to go back to the blackboard, to look for what other designers had potentially missed in their implementations for a device that would be willingly taken up by practitioners. This requirement also reinforced the need to make the most of our contact time with the chemists, which lead to our development of the tea analogy.

After our first two instantiations of the making tea experiment, we went back to the lab for follow up observations and interviews. We watched more experiments in progress, and in particular, we took new copies of actual lab books. After having done tea, we were better able to parse what was recorded. We could begin to validate for ourselves how closely tea seemed to be mirrored in the actual lab books. In our interviews with chemists about their recording processes, again based on what we'd learned through tea, we were able to tease out under what circumstances recording practices may differ. For instance, novel or particularly hazardous experiments were written out in substantially more detail, with many images hand drawn to capture the process.

Making tea before this set of interviews gave us an improved conceptual lexicon with which we could engage the domain experts on the design problem to be modeled. Beyond discussing the functional aspects of the lab book, we could also engage in more effective questions about the experiential qualities of the book itself.

Figure 6. Inside view of A fume cupboard. 2 chemists usually share this space at a time.

4.2 Enhancing Software Design

In our project, we were not only interested in designing the user interface and physical affordances for a lab book replacement. We were also interested in designing appropriate software tools and process models to support the interaction design. Based on the first two iterations of tea, we were able to develop a provisional process model [17] for the making tea experiment (Figure 7).

This enabled us t**o** understand the information flow for the services we would have to coordinate in our design, and gave us a reference frame for taking up architectural issues with the other members of the team involved in software architecture and service development. Our goal here was to be certain that we could derive a general case from tea using the tea process model. Just as we tested our making tea-derived prototype with domain experts, we tested this model of the tea experiment against a formal write-up of an experiment to make aspirin. The model held. We continue to use this model in discussions for service discovery throughout the lab environment and out onto the Grid.

It is of course necessary to develop design specifications for both the user interface and the software for a system. It is not always the case that the results from the analysis of the interaction process can be so readily repurposed to derive the software specification.

5. ASSESSMENT OF METHOD

Based on previous experience within the team for developing interactive systems for complex domains, we found that making tea significantly improved our efficiency in developing and testing candidate designs. Within the design team itself, it became a touchstone to which we could regularly refer for communicating queries about process and for questioning our assumptions about a particular design decision. It is not unusual to have models of artifacts one is building. In our case as well, our tea model served to keep us focused less on an artifact and more on the processes of the people for whom we were designing. The model was understandable enough to allow us not to get caught up in the complexity of the process, but to still have the context of the process available as we focused on the artifact of concern: the lab book and how the chemists interact with it in recording an experiment.

As stated above, making tea helped us leverage our site observations and interviews. It let us within the team do fast checks throughout the process with our domain experts on focused questions via tea.

Making tea did not make us domain experts, which may have impaired our ability to *see* processes that become invisible to experts through familiarity. It did, however, give us a domain insight that let us focus our observations and time with experts on particular parts of the process that we were most concerned to understand about the recording process in an actual environment. Our making tea recordings gave us a bench mark against which we could assess the degree to which different chemists created their write ups distinctly or similarly to our model, and what affordances/constraints we would need to design to support this set of practices. It was through these comparisons, for instance, that it became apparent how critical supporting hand writing and drawing for in-lab annotations would be.

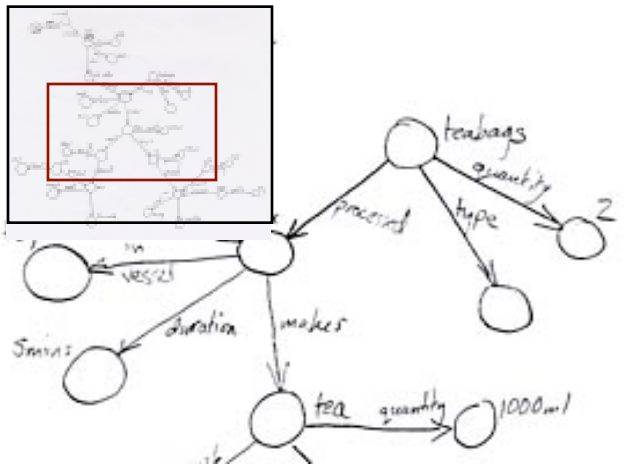

Figure 7. Zoom in on process graph of the Making Tea experiment. Complete graph inset upper left.

While it is likely the case that many of our design findings may have been achieved over time through more traditional observation or expert artifact walk-throughs, the use of analogy gave us sufficient domain insight in order to maximize and effectively accelerate the observation, interview, and task analysis stages towards early and effective design reviews of lo-fi prototypes.

Our analysis of these processes in the context of making tea also informed the type of evaluation method we would need for our final prototype. The particulars of our evaluation approach are described in [20]. In brief, because we were concerned with designing *usable* tools, we wanted to understand if the artifact we designed was usable. Our criteria for use throughout the design process had been that the tool would digitally emulate both functionally and experientially the qualities of the paper based lab book. We put the artefact into the hands of 3 chemists who carried out 4 real

experiments in real lab conditions, with other chemists using the space as usual. Our benchmark was that after ten minutes of use, the chemists would forget about the tool and just use it as they would a lab book; our second criteria was that they would be able to record all their information and jottings as they usually would with a paper book. Dylan's *Process Outcome Affect* evaluation model [9] was used as a way to assess these criteria. The end result was a very well received prototype that is the basis for two other systems, one for undergraduate chemistry labs, and one for bioinformatics lab annotations.

Additionally, the approach gave us the means to rapidly and concurrently develop a system model for the services we would develop to support the prototype. The Tea experiment has become the benchmark for testing these other aspects of the system such as our ontology building: our initial tests are "can we model tea on this first" before testing any more complex process. Again, we understand tea; we can use it to inform ontology and architecture models, which can then in turn be used on our part to communicate systems processes where we are domain experts, back to the user community – chemists – to solicit their feedback to help validate our models.

As a social catalyst, the use of making tea also helped build a simpatico between the chemists who participated in the design and evaluation sessions, and the design team. We suspect that, more than just using a single real experiment as a point of reference, having tea in common took the chemists outside of their provenance just enough to give them a keener sense of what we were trying to do as designers. By both groups speaking "tea" we created a shared experience, and a shared goal in which the chemists participated for short periods as active design review informants, consultants and models of practice. This engagement is distinct from participatory design where the stakeholders are actively involved in the specific design of the artifact. The shared experience of making tea, however, gave our participant chemists a sense of being involved in design in an analogous way to which we were involved in chemistry.

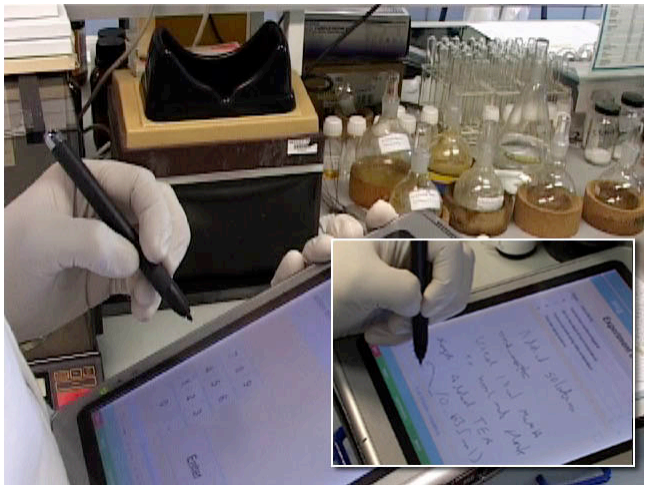

Figure 8. The lab recording service, shown here being tested in real lab conditions with a real experiment. We delivered a suite of services designed to support interacting with various devices and processes in the lab. We deployed these services in a single lab book-like form factor on a tablet PC, in particular to support the drawings and annotations (inset, lower right) on those experiments.

In our evaluation of the working prototype (Figure 8), chemists used our lab book suite of services to carry out their regular experiments in their own lab environment. In our post use interviews with the chemists, they remarked that they were surprised how we had been able to capture so much about their work process considering the actual number of contact sessions we had with them over the design period. This reinforced the sense we had that we had been able to maximize the efficacy of our contact time via our iterative interrogations of process with making tea.

6. FORMALIZING TEA

We suggest that tea is a useful method for design situations in which there is an expertise gap between the design team and the domain for which the design is to be deployed. In this section we suggest some guidelines for using making tea in such a situation. The first question may be is an analogy required? The process itself may be directly translatable for the design team, in which case this method may hinder rather than support the design process by being concerned with staying true to the analogy rather than using what works for the given context.

If the use of analogy seems like it may help focus the design process and assist exchanges with the domain experts, then the fundamental requirement of this method is to ensure the validity of the analogy to be used. In canvassing other domains, we have found, quite reasonably, that the domains experts themselves frequently use analogies to explain processes. They are the best source for proposing a set of possible analogies to be used. It is then up to the design team to decide on which of these analogies have the most resonance for the majority of the team. Since the team will be using the analogy as a communication tool throughout the design process, comfort level with the analogy is important. In the above case, we chose tea over martini making or cooking soup although each analogy passed the validity test for modeling an experiment. For the group, tea simply felt better.

Engaging the potential design participants early in the design process also helps to build an understanding of the design team's goals.

As we mention in section 3, we had a domain expert on our software development team. He ran the making tea experiments and responded to our initial process questions, which we then validated through our observations, interviews and design reviews with the domain experts. It was obviously a great benefit to have that local expertise on the team. If something came up in the design process where we were uncertain of our ground, we could "speak tea" with our expert, and get back a tea-based reply, or a "this is how this differs from tea" reply. It was critical for these exchanges that our domain expert would speak tea with us.

Likewise, it would not have been possible to use the tea experiments without a chemist to run them and translate the distinctions between tea and chemistry. We simply could not have used these sessions to elicit the information about the process without that expertise. This is not to say that the analogy method cannot be used without the regular presence on site of a domain expert. It does mean, however, that in the initial stages of working through the analogy as detailed in section 3 above, a domain expert is critical to working through the analogy towards design prototypes.

Once the design prototypes have been established, it becomes possible to communicate with the expert less frequently, as long as the opportunity for continued checking about design questions remained open. These queries could be carried out by email or phone. Indeed, as we have been building services to support the lab book, this is exactly what has been happening: we can develop more components with less frequent contact with our domain expert, freeing up that expert's time for work on other projects. That contact, through tea however, still continues.

7. CONCLUSIONS

In this paper we present Making Tea, a method for designing interactive systems by an analogy collaboratively developed between the domain experts and design team.

Making Tea is an amalgam of methods: we used it to improve the quality of our limited opportunities for ethnography, expert interviews, expert participant design reviews and system design modeling. We see its main strength as a way to help leverage those techniques to maximize their benefit for user centered design practice. We were particularly impressed with the results they afforded us in this challenge with designing a lab book replacement system for synthetic chemists. The success of the eScience project as a whole is in no small part determined by how useable the tools will be which will support practitioners to transferring current analog work practices to new, pervasive digital systems. In the lab book domain, there are many known, unused systems. To quote Alan Dix, "if a system isn't used, it's useless" [11]. Making Tea helped us develop a system that was used. Our results give us confidence that the Making Tea method can also be deployed in other design contexts for elicitation in highly expert, longitudinal and loosely structured tasks.

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