Beyond a Faster Horse: the UX of a Paperless Biochemistry Laboratory

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Abstract
It is astounding though possibly not surprising, that the default cognitive prosthesis in the modern laboratory environment is the paper notebook. In many walks of life, the 50+ year-old promises of technology are increasingly a reality: spoken dialogue systems a commodity, central-heating systems that can anticipate need and context-aware delivery of advertising as you walk past a shop. With all of this capability, why are paper notebooks still the best option for many working in science laboratories? This paper describes a study designed to try and understand why paper remains prevalent. It seeks to understand what feature set and design decisions are required to inform the design of an Electronic Lab Notebook (ELN) capable of displacing the paper notebook.

1. Introduction
Henry Ford famously posited: "*If I had asked them what they wanted, they would have said a faster horse*". The type of transformation to personal transportation brought about by the motor car is in some ways similar to what we seek to achieve with the electronic notebook (ELN). We are not simply looking for a digitised version of what scientists currently do in a note book, One Note or Evernote already provide this and are used with mixed success. We are looking for a transformative tool that understands the array of stakeholders engaged in science and the complex environment and geography where this work takes place. The challenge of UX is not to simply ask users what they want, rather it is to work with them to understand what they need. This work in progress paper is arranged as follows. First, the context for the ELN will be described, outlining the locations and range of equipment used, by whom and crucially what type of tasks need to be supported and documented. This paper will then go on to describe the approaches proposed to capture stakeholder insights. Finally, some preliminary finding shall be presented.

1. Many ordinary users in an extraordinary environment
A biochemistry laboratory is a nuanced, complex and sometimes hostile environment. Depending on the task at hand, there may be a range of health and safety requirements that can inhibit the typical user's abilities. At a minimum, a user will employ gloves, eye protection, and a lab coat. Depending on the substances used, they may require to work in a fume hood. This is an enclosed compartment with a sliding-front window, or sash, that can be drawn down to prevent contaminants entering the working area, or conversely, protect against toxic fume exposure or chemical spills. In some cases, these precautions are in place to protect scientists, though often these precautions aim to preserve the integrity of the experimental sample. It is also common for areas to be dedicated for the sole purpose of a single activity, such as tissue culture. Therefore, it is likely that the execution of an experiment will take place in a range of locations which are dependent on the particular action being performed.

This environment is peppered with equipment; in some cases, it will be for the sole use of an individual, e.g. microfuges, shakers, heat blocks or pipettes. Where equipment is more expensive, or perhaps used intermittently, it will be shared with others. This may be a resource for dedicated laboratory use, or for use within a wider department or an entire institution. In addition to the equipment used to manipulate and interact with experimental samples, there will be a range of plasticware consumables such as pipette tips, tubes, columns, and tube racks. There will also be various chemicals and biochemicals used at different stages of the experiment. Some of these items will be stored at room temperature on shelves and many will be stored in refrigerators or freezers. It is typical for an individual scientist to have one, or more, personal refrigerator and freezers. The owning scientist can then use these to store personal stocks of everyday items or experimental samples they are currently working with. Other items may be stored in communal locations within a laboratory space. For long term storage, there will be institution-wide resources that can be utilised.

The laboratory is inhabited by a range of intelligent, driven individuals that must execute experiments methodically as they interact with the wide range of complex instruments, equipment, chemicals and bio-chemical stock described previously. There will likely be an array of different stakeholders in a laboratory environment. This can include principal investigators, postdoctoral researchers, Ph.D. students and undergraduate students. Additionally, in some cases. there also may be support technicians and laboratory managers. Although this network of stakeholders strive to fulfil a common, overarching goal of delivering insights via high-quality science, their individual contributions will vary and thus the supporting tools must fit a range of user needs. Occasionally, there will be overlapping and complementary goals, and in other cases goals may conflict.

Science is a highly collaborative environment, not only within laboratory groups but across different geographic sites. Modern scientific studies tend to employ a multifaceted approach requiring a wide range of expertise often found across multiple institutes. Currently, a lot of computer-supported collaborative work is supported via fairly primitive tools such as email and online file stores. Perhaps unsurprisingly, spreadsheets feature heavily. This is a good example of a single-use data repository; a spreadsheet manifest which describes the contents of a sample delivery is disposable and has a very short half-life. Once the delivery is received, the manifest file is of little value and will most likely be archived or discarded.

The design, execution and reporting of an experiment will happen across a range of locations, over an extended time period and with various stages requiring different types of support. The collection of stakeholders described will perform different roles in supporting these tasks. Each role will have different expectations and require different levels and types of assistance to produce good science. The cornerstones of good science are robustness, reliability reproducibility. We can assist in forming a foundation for this through effortless access to experimental designs and meticulous capture of experimental metadata. The current approach with personal, paper-based notebooks only serves to support the individual in isolation. This is not at all surprising, as the notebook is a cognitive prosthesis for the individual as they discharge their duties. We propose that, with a rich understanding of the interconnected web of stakeholders, it is possible to design a system that can provide a highly flexible, personal support tool that can also inform the wider challenge of collaboration, research project-management and facility management.

In summary, our problem space is high dimensional and complex. We have a range of different stakeholders contributing different effort to a central goal. The physical environment is varied and presents some significant design challenges. Within this environment, there is a vast array of specialist equipment and consumables, all utilised to perform high-quality scientific research which must be consistently executed and meticulously documented. Projects can have durations varying from months to years and often involved collaborator's spanning different geographic locations. This study aims to improve the understanding of the work the scientist performs, discover the everyday tools and technologies they currently employ and explore the different priorities of various stakeholder groups to inform features required of an ELN.

2. Study design

Although the software development team has over 10 years of experience delivering software solutions for scientists, we were keen not to limit our findings by our experience and assumptions. To that end, this study has been designed to be open and unbounded but adheres to many of the characteristic of a Semi-structured qualitative study (Blanford, 2013). User time is a valued commodity and to ensure maximum return, a phased focus group (Gill et al, 2008) was devised to address the following three questions:

1. What tasks make up a typical day of work for a biochemical scientist?
2. What tools and technologies are routinely used to support the tasks described in Q1?
3. What are the scientists priorities for an ELN?

Participants for the pilot were recruited from the Lamond Lab group and verbally consented at the beginning of the session. Participants were guided through three tasks addressing each of these research questions. A facilitator introduced each task and offered points of clarity and rationale. The study had a purposeful, well-defined structure, however the intention was always to capture core data whilst seeding relevant, reflective discussion within the group. The session was audio recorded and a second facilitator was also present to take notes as well as prompting the group with regards to timings, etc.

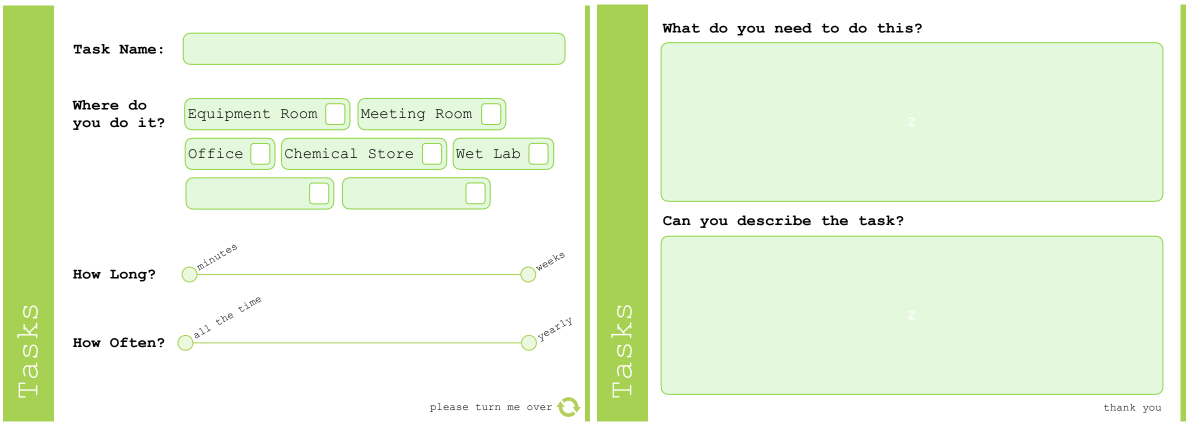

Figure 1 – Task postcard, front and rear.

Questions 1) and 2) were addressed using a lightweight, staged, survey card approach. To address question 1), participants were given a stack of custom-designed postcards where they could fill out the task's name, location in which it's performed, duration and frequency. This was intended to be a quick-fire activity. To reduce participant effort and encourage a flow state (Nakamura & Csikszentmihalyi, 2014), the postcard (fig 1) design offered checkboxes with common locations and visual analogue scales (Krosnick & Fabrigar, 1997) representing duration and frequency. When the completion of cards by participants came to a natural rest, the facilitator directed participants to turn their cards over, where a small free-text box asks participants to provide a brief description of the task and indicate items that are necessary to perform the task. This takes a little more effort. Upon completion of these postcards, each participant is encouraged to identify their most frustrating task and share this with the group to seed a wider discussion. To address question 2), the front face of the card captured identical metadata to question 1), whereas the reverse face of the card requested a description of the tool's use with space to list associated pros and cons. When participants had completed the support-tool cards, they were asked to order them from most useful tool to least useful tool. Each participant was asked to describe their most indispensable tool.

To address question 3), a closed set of 13 terms, pertinent to ELN, was generated. As a group, the facilitator leads a collaborative insertion-sort of the terms. When a new card is presented, the term is described by the facilitator and a shared understanding of its meaning is agreed on by the group. The new card's importance is then discussed in relation to each existing card in the list, generating a prioritised list. The purpose of this exercise is threefold. Firstly, to ensure the development and design teams understand the key vocabulary as defined by the users. Secondly, to create a prioritised list of important features that can directly feed into our development process as we begin construction of our product. In future, It will be interesting to observe the differences, if any, there are between stakeholder groups. Thirdly and finally, performing this exercise as a group was a conscious design decision to encourage externalised reasoning. If there is a split of opinion in the group, each party must articulate their argument for and against. This type of collaborative reasoning also helps users understand the compromises that must be made as part of the development process.

3. Preliminary findings

The study design described was piloted with six scientists from the Lamond Laboratory based in the Centre for Gene Regulation and Expression within the School of Life Sciences at the University of Dundee. These scientists were all experienced, postdoctoral researchers who were working on various projects in a subfield of molecular biology known as proteomics. The session lasted for 1 hour 22 minutes and there were no deviations from the design described previously.

3.1. Task card findings

For the initial exercise, 30 task cards were completed. These cards were sorted post hoc by the facilitator into five emergent themes. **Sample Preparation** was described on 16 cards, with a wide range of noted durations, from one hour to three days; these activities are performed frequently and exclusively in the "wet" laboratory. **Sample Processing** - processing samples on the mass spectrometry (MS) instruments - was the second-most reported task with six completed cards; the duration of these tasks ranged from two hours to two weeks and they were also reported as frequently occurring, unsurprisingly occurring exclusively in the instrument room, where the MS instruments are housed. **Tissue Culture** was the third-most reported task with three completed cards where durations ranged from 30 minutes to one day, occurring anywhere from daily to monthly. This activity happens in a separate, secure "wet" laboratory space which provides a stronger degree of control over air flow, etc. **Data Analysis** was the fourth-most reported task with three cards with durations from three hours to multiple weeks. This activity is discharged in the office space generally involves a range of domain-specific software packages which process the raw files generated by the MS instruments. **Literature Review** was also reported on one card, with a duration of three hours at a weekly frequency.

There was some consensus in the group around tasks that frustrate; these included activities that are perceived to waste time, failed quality controls, instrumentation/equipment failures and external dependencies such as engineer call-outs. MS systems are incredibly fragile and require regular, preventative maintenance and cleaning. The task cards and discussion indicated that a large portion of a scientist's time is spent doing bench work, performing experimental steps using equipment and consumables.

3.2. Supporting tool card findings

For the second exercise, 18 tool cards were completed and sorted into another five emergent themes. **Domain-Specific Analysis Software** was reported on five cards, extending in duration from minutes to days. These tools were reported as being employed frequently to weekly, occurring in the office. **Simple Bench Kit** was reported on four cards, with a frequency of constant use in the "wet"-laboratory location used for durations ranging from minutes to hours. **Process Tracking** was reported on four cards with a frequency of constant use, durations between 1-20 minutes and with dual locations of office and instrument room. Many participants reported using paper notebooks for process tracking. Flexibility and portability were noted as important, positive aspects of paper notes and several participants reported that the act of handwriting their notes assisted with memory retention. An interesting duality emerged whereby many scientists keep a "scratch" notebook where rough notes and ideas were captured, which were used to inform formal notes in a paper laboratory notebook, Microsoft Word document or similar. **Non-Domain Specific** software, predominantly Microsoft Excel, was reported on four cards with a frequency of constant use and duration ranging from minutes to hours. The positive attributes for Microsoft Excel were reported as its ease-of-use, flexibility and wide range of accessibility to many different stakeholders. The final tool noted was **Internet Journals**, used every day from minutes to hours.

The flexibility and portability of paper notebooks will always be hard to compete with. The added value of an ELN will come from opportunities which integrate additional, required support tools. The flexibility of Microsoft Excel is tempered by the duplication required to repeat routine tasks. Arguably, where a routine task is consistently performed in Microsoft Excel, e.g. calculating volume required for desired solution concentration, it should be possible to reduce the work done by the user to initialise this type of spreadsheet calculation. In addition to reducing the effort required from the individual, the likelihood of an error occurring is also reduced. Tools like Microsoft Excel can be regarded as unmanaged and therefore any audit trail is very much at the discretion of the user, dependent upon their personal habits of file management such as organisation and backup. An additional opportunity to reduce the scientist's work, whilst simultaneously improving metadata capture, is to model all aspects of their scientific process. If an experiment requires a specific reagent and this reagent is modelled in the system, then there is no need for the scientist to manually note the batch numbers, etc. The user can simply form a digital association with an existing stock item, using a pick list or even a barcode attached to the physical stock item.

3.3. Priority sort findings

The final task of insertion card sorting stimulated a good deal of conversation. This was the final task performed and provided a good opportunity for group discussion. The agreed upon final list of ordered cards is presented in table 1, with accompanying remarks.

Position	Term	Remarks
1	Security	No ambiguity or surprise that this is paramount
2	History/Audit Trail	Immutability is important as "crossing out" of mistakes needs to be transparent and logged, much like a legal document.
3	Calculations	Calculations are done very frequently, on the fly at the bench. Smartphones are very frequently used as calculators.
4	Protocol (SOP in dev)	Access to the software on mobile device described as essential. Would be ideal for dictating verbal notes, scanning barcodes, taking pictures etc.
5	Standard Operating Procedure	
6	Portability	Access to the software on mobile device described as essential. Would be ideal for dictating verbal notes, scanning barcodes, taking pictures etc.
7	Location Management	
8	Notifications	Notifications are perceived as being more of a hindrance than a help. Very negative reaction to the idea of receiving notifications, other than those from personal timers. Otherwise, a very useful exception for notifications would be MS alerts for calibration/failures.
9	Sharing	Choosing which users can have access/share your experimental data is very useful.

Table 2 – Card Sort.

The term **Standard Operating Procedure** (SOP) was disambiguated with **Protocol**. Where a protocol is an experimental design in-progress, which may be used numerous times, being tweaked and modified as per the scientist's desires. In contrast, an SOP is regarded as a fixed experimental design that should not be deviated from. In the context of academic research, a facility's protocols are far more prevalent than SOPs.

The term **Notification** evoked a strong negative response from the majority of participants. There was a strong feeling that notifications were an unwelcome distraction and intrusion into their work. This topic was explored further by discussing the extent to which participants tuned and managed notifications they receive on their personal smartphones. For instance, Facebook notifications may be turned off, SMS messages may be visible but not audible, and calls from certain numbers may have an associated ringtone compared to unknown numbers. The range of notification configurations that participants had on their smartphone's was quite interesting and was used as an analogy for the *ELN* app. The participants then spent some time thinking about information they would want to know about in the form of a push notification. For example, if an instrument was booked for in a week's time, but has since developed a fault. Or, when a crucial reagent which is close to expiration. The important lessons learned were that "push notifications" is predominantly an engineering term. When presented to the user, it requires a few leaps to determine the value it may add to them. This illustrates that potentially valuable features run the risk of being dismissed as it lacks an interpretable, obvious value for those in the room.

4. Conclusions

The intention was to design an engagement exercise that could be delivered in one hour to a wide range of stakeholders and deliver insight into the daily life of a laboratory-based scientist. This exercise needed to answer simple questions relating to routine tasks and the technology employed to support them. Despite there being an existing relationship between participants and participants being in relatively small number, new information was certainly obtained. The run-time of the exercise was possibly longer due to this familiarity within the group and various informal chat which was interspersed. It is, however, important to establish a rapport with the participants to ensure a rich dialogue. Moving forward, we intend to recruit further participants representative of the various stakeholders in the described problem-domain. This will enable us to methodically broaden our understanding if the rich network of stakeholders engaged in life science research.

5. References

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