“Good artists copy, great artists steal” - p.picasso

- a study of design principles used in development of a user-friendly system

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Abstract

This paper examines the most significant guidelines for developing a modern, tactile, intuitive user interface, applies them to a system and measures their impact on the systems usability. A group of eight system users were selected to run through a real-life scenario, using an active bioreactor controlled remotely by the users, as efficiency and error-rate were measured. Through the analysis of user survey-results as well as recorded screen-interactions and face-monitoring, this paper measures the usability in the system and seeks to determine which usability design guidelines are responsible for the results.

The paper finds clear evidence to suggest that by adhering to a select number of design principles and guidelines it is possible to dramatically improve usability in even the most complex systems. Namely, by working with context-aware information, using the 80%-rule, and leading the user through tasks with contrasting colors and varying sizes of text, we can bring consistency and intuitiveness to the user interface experience. By designing a system with high usability the users will work faster, more accurately and make fewer errors. In addition, an intuitive user interface requires less time and effort to be spent on training.

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1 Introduction

A system is never more effective than the user controlling it. With this in mind designing a good user interface is about unleashing the full potential of a system and empowering the user. But what factors determine if a user interface is good or not? According to Apple, who is a market-leader in user interface and product-design it is all about a few key criteria. They are of course standing on the shoulder of giants in the field of usability, however they seem to have perfected the formula. This paper will look closer at what their recommendations and advice are, adding to the equation theories from esteemed authors such as Nielsen and Norman, then shake and stir. The resulting cocktail will be applied on a product far from what Apple is known for, namely a bioreactor.

If we design a bioreactor as if it was a trendy consumer-product, will the end-result be a better experience for the users, leading to less problems and a more empowered user-base? Or is visually appealing, tactile user interfaces primarily for consumer devices? That is in its essence what this paper will try to answer.

1.1 Definitions

Human-Computer Interaction (HCI) - the study, planning and design of the interaction between people (users) and computers[1].
System - The term "system" in this document is used both for the unit itself as well as for the software in question.
Use case - A use case in software engineering and systems engineering is a description of steps or actions between a user and a software system which leads the user towards something useful[2]
User interface (UI) - the visual part of a software-system
Usability - According to ISO standard 9241 - The effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments[3].
User experience (UX) - User eXperience concerns the way a person feels about using a system[4]. User eXperience (UX) concerns the way a person feels about using a system. User experience highlights the experiential, affective, meaningful and valuable aspects of Human-Computer Interaction (HCI) and product ownership

1.2 Background

The purpose of this paper is to review the role and impact of usability in user interface design. This paper is an assignment in computer science bachelor degree where the aim was to use scientifically-based and well-established theories to analyze how user interfaces are used to bridge the gap between machines and humans. Whenever a user interacts with a user interface it is with a goal in mind, and with that a dialogue

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[1] http://en.wikipedia.org/wiki/Human_computer_interaction [2011-05-29]

[2] http://en.wikipedia.org/wiki/Use_cases [2011-05-30]

[3] http://www.w3.org/2002/Talks/0104-usabilityprocess/slide3-0.html [2011-05-25]

[4] http://en.wikipedia.org/wiki/User_experience [2011-05-25]

between the system and the user commences. Depending on how successful this dialogue is, one can say a system has good or bad usability. The more the user interface functions according to the users expectations and previous assumptions, the more successful the user will be. This paper will review some common principles, see how they were applied in developing a system and assess the results.

User interfaces are found on devices everywhere – from common household appliances to complex industrial systems such as nuclear power-plants. The main characteristics driving the choice of an interface is the need for humans to monitor, interpret and control the behaviours of complex systems. Advanced systems often have many more factors than one person can rapidly comprehend or react to. The user interface is seldom responsible for the actions taken, but how it functions and relays information informs the user – thereby directing his or her actions. As such, it should be understood that a poorly designed user interface results in low usability which can in effect cause erroneous interpretations and actions from the user.

A good user interface should not obscure the information the user is looking for, nor confuse the user in terms of what actions needs to be performed in order to achieve a sought-after result. A successful user interface is simple, but constructing it is far from easy. Identifying which design factors make a complex system simple to interact with from a user's perspective is key. This challenge has served as an inspiration – shaping the questions this papers sets out to answer. A successful user interface design process is as much about re-invention as it is about drawing from what others have done and what is already established, hence the title of this paper.

1.3 Purpose

The purpose of this paper is to identify which key-characteristics in an existing user interface that are critical to making a user interface intuitive and successful. By looking at the development of a user interface for a complex system, which has simplicity and reduced error-factor as key-goals, this paper hopes to go beyond discussions on previously established theory. Instead gauging theoretical accuracy through a real-world example.

1.4 Problem

This paper will review the steps that were taken to identify and encourage correct behaviours on the part of the user, and examine how they relate to established theory. This paper will examine to what degree these steps could be considered successful.

1.5 Delimitations

Because we didn’t perform any tests using a touch screen, it was not possible for us to determine anything about the success-rate of the tactile aspects of the user interface.

1.6 Hypothesis

The main hypothesis that is tested in this paper is whether a user interface designed using a select few design guidelines will make users more comfortable in using the system?

Secondly, if the users feel more comfortable interacting with the interface, does that mean they make less errors?

Finally, the paper aim to test whether the use of varying sizes and colors in the interface make a system easier to interpret and understand as well as making the interface more efficient in communicating the system's current state and helping the user identify anomalies.

2. Theory

2.1 Established theory

2.1.1 The art of usability

Usability is a field that aims to increase productivity and decrease costs from a user point of view [Butler 1995:1]. Usability has been considered a relevant factor of a the overall quality of the system ever since interactive interfaces was introduced [Butler (1995:1)]. In earlier days, a system with high usability equalled a system with much functionality. Lack of usability was measured simply in how many features the program could help the user with [Allwood (1998:10)]. For the user to be able to take advantage of features offered by the system, training was required. For many years, competition between system-development companies was based on who provided the most functionality and not about how this functionality was presented. Lack of usability in a system can seldom be circumvented by increased training since it inherently also adds increased workload and decreased available time in a work-environment [Butler (1995:1)]. Reduced costs related to good usability in a system can be found in reduced amount of required training, increased end-user satisfaction and reduced dependency on support [Butler (1995:2)].

According to Butler the term "usability" contains several topics such as simplicity, intuitiveness in interfaces etc. [Butler (1995:2)]. From a user's point of view a system is supposed to provide functionality and data to facilitate a user's tasks. User interfaces assist the user in controlling the system and making information available [Butler, 1995:4]. Butler goes on to state that user interfaces map different layers within the system to layers in the mind-frame of the user. The success of the user interface is in direct relation to how well this mapping works. When said mapping is working well, the usability of the system is high [Butler 1995:5]. The presentation of a system should adjust itself to the task the system aims to perform or the message meant to be conveyed [Hallnäs & Redström (2002:3)]. The users ability to understand and interpret a system's interface is rooted in the user's social, cultural and organizational behavioural patterns, which is why different users could have different interpretations of good usability [Chamorro-Koc, Popovic & Emmison (2008:2, 5)].

Usability also involves following conventions and perceptions of the assumed users contextual realm [Apple Human Interface Guidelines (2011:1-1)]. One example of this is using metaphors. Metaphors are fundamental pieces in a users conception of how a particular task should be executed [Apple Human Interface Guidelines (2011:3-1)]. By utilizing established analogy one borrows from the users existing experience to make the system more understandable and let the users assumptions direct them in function. As an example Butler highlights the "desktop" as a virtual space within our computers [Butler (1995:8)]. According to Apple a system can be considered user-friendly if it strives to stay in the mental frame of the user and has four distinguished characteristics:

- Familiarity - The user's mental model is based primarily on experience. When possible, enhance user interface components to reflect the model's symbology and display labels that use the model's terminology.

- Simplicity - A mental model of a task is typically streamlined and focused on the fundamental components of the task. Although there may be myriad optional details associated with a given task, the basic components should not have to compete with the details for the user's attention.
- Availability - A corollary of simplicity is availability. An uncluttered user interface is essential, but the availability of certain key features and settings the user needs is equally so. Avoid hiding such components too deeply in submenus or making them accessible only from a contextual menu.
- Discoverability [sic] - Encourage your users to discover functionality by providing cues about how to use user interface elements.

  [Apple Human Interface Guidelines (2011:40-41)]

2.1.2 What does it mean to be intuitive?

The definition of "intuitive" is a topic of continuous research. On the topic of user interfaces, it describes an interface that the user, without knowing why, feels an inherent understanding of. The two components used to establish an intuitive interface are first, basing it on the mental model of the expected user and second, striving to give user a sense of "flow". Flow is a concept brought to the discussion by Mihaly Csikszentmihalyi in the book "Flow: The Psychology of Optimal Experience. In the book "About Face 2.0 - the essentials of interaction design" by Cooper and Reiman, flow is summarized as "when people are able to concentrate wholeheartedly on an activity, they lose awareness of peripheral problems and distractions". When a user is in a state of flow they are extremely productive and can sense a state of euphoria. A successful user interface is enriched by promoting and enhancing said flow. If the system constantly interrupts the user or breaks the flow the user becomes increasingly unproductive, makes more mistakes and might develop feelings of frustration [Cooper & Reiman (2003:119)].

The authors of "About Face 2.0" goes on to state that the less the user has to interact with your interface, the better it is for the user. As such the user interface must at all times be at the service of the user and be as transparent as possible. Four main characteristics to reach intuitive interfaces are:

- Follow mental models
- Direct, don't discuss
- Keep tools close at hand
- Provide modeless feedback

  [Cooper & Reiman (2003:120)]

A mental model is a simplification that the user makes to understand the inner workings of a system. Whenever you press the brake on your car, you don't think of the hydraulic cylinders, tubing and metal pads that finally press against a perforated disk. Instead the idea of *breaks* becomes a pedal you press down that causes the to car slow down in relation to how hard you press it. This is the users mental model of a mechanical process [Cooper & Reiman (2003:23)]. The closer to a pre-existing mental model of what the system does a user interface can be, the easier it will be to bridge the gap in understanding between the user and the system.

2.1.3 When is something successful?

When doing measuring or performing tests it is important to establish what defines a successful result. This determines in part what to look for, but also what tools to use. Success can be measured by time to task-completion, the minimization of errors or the amount of training required to operate the instrument competently. Other areas that are commonly defined as focus of interest is how the user interacts and interprets the system. Jakob Nielsen is an acclaimed author in the field of usability and user interface design. Defining what determines if the system is successful is, according to him, essential. He provides a list of five important points to assess:

- Learnability [sic] - How easy is it for users to accomplish basic tasks the first time they encounter the design?
- Efficiency - Once users have learned the design, how quickly can they perform tasks?
- Memorability - When users return to the design after a period of not using it, how easily can they re-establish proficiency?
- Errors - How many errors do users make, how severe are these errors, and how easily can they recover from the errors?
- Satisfaction - How pleasant is it to use the design?

[Jakob Nielsen, http://www.useit.com/alertbox/20030825.html 2011-05-19]

In the earlier chapter "The art of usability" a list of characteristics that Apple deem important for usability is presented. This list goes hand in hand with Nielsens suggested critera. Familiarity, Simplicity and Availability address Learnability, Efficiency and Memorability whereas Discoverability could be related to Satisfaction in Apples definition. If using Apples guidelines when designing, then Nielsens items could be used to test the results.

2.1.4 Defining users with Personas

By utilizing various tests and measurements one can get a lot of valuable data about the users, but it is easy to lose sight of the "real people". This can be remedied with Personas [J.J. Garrett (2011:49)]. By establishing a persona as a unique understanding of the users needs, expectations and pre-disposition to use the system is established. Cooper and Reimann state "The best way to successfully accommodate a variety of users is to design for specific types of individuals with specific needs" [Cooper & Reimann (2003:56)].

As stated in Gulliksen *et al*. (referring to Calde *et al.*) "user models, or personas, are fictional, detailed archetypal characters that represent distinct groupings of behaviours, goals and motivations observed and identified during the research phase". Cooper (1999) elaborates further on the concept by establishing that "the purpose is not to give a precise description or a complete theoretical model of a user. Instead it is aiming at a simple, but good enough description of the user to make it possible to design the system".

2.2 Applied theory

2.2.1 A primer in Bioreactors

A bioreactor is commonly a device used to grow cells or tissues from cell culture. Common applications for bioreactors are production of Monoclonal antibodies (mAbs), therapeutic proteins, viruses and vaccines, stem cells, personalized medicine and biosimilars. The cell culture is placed in a vessel or specially engineered plastic bag inside the device containing medium. The conditions inside the bag is crucial for the growth-rate of cell culture and it is the responsibility of the bioreactor to control the factors affecting said conditions. Bioreactor design is considered a relatively complex engineering task where several finely tuned sensors need to interact in adjusting the environmental conditions of the medium. Normally the values are pre-defined by a user and the machine is responsible for maintaining these conditions through the length of the run.

Critical factors for the machine to monitor and regulate are oxygen, nitrogen and carbon dioxide levels in what is called the gas mix. The main responsibility of the reactor is to continuously adjust the flow rate of said parameters according to the culture's current state. Furthermore the cell culture's environment requires closely controlled levels of temperature, pH, dissolved oxygen and the circulation rate which is regulated by agitation-supply [Eibl & Eibl (2011:15)]. The circulation-rate is in itself a complex topic and one of the main differences between different makes of bioreactors on the market. The purpose of circulation is to transfer required oxygen into the solution but also to help mix nutrients and aid in the fermentation-process. Since this is accomplished by creating an artificial momentum in the medium there is a risk of generating shear-stress on the culture, negatively affecting growth [Cabral, Mota & Tramper (2001:406-408)]. "An ideal disposable bioreactor should be able to achieve fast mixing while maintaining low agitation shear stress, which can broaden the potential application of shear-sensitive cell lines" [Eibl & Eibl (2011:15)].

2.2.2 Design & human computer interaction

In designing user interfaces a lot of established theory exists. This is the result of previous development and testing and it has been formalized into principles, guidelines and standards by different authors in the field. The general consensus on the differences between the three types of theory is in terms of authority. Principles are understood as having low authority and generally consist of abstract design rules. Standards have high authority and are very specific in their design rules whereas guidelines have a more general application and also low authority.

Among the plethora of guidelines available, the gestalt laws of perceptual organization is widely accepted. These describe how humans inherently group information, namely:

- Law of proximity - Objects near each other tend to get grouped together by the user
- Law of similarity - Objects looking like each other are more related than if they just are close to each other
- Law of Pragnanz - Reality is organized or reduced to the simplest form possible

Norman's model of interaction is one of the most influential in the science of human computer interaction and aims to provide an understanding between the human and the computer. It clarifies strategies on how to layout and think about structuring your information in a user interface, but also approaches to user interface interactions.

Normans seven principles:

1. Use both knowledge in the world and knowledge in the head
2. Simplify the structure of the tasks
3. Make things visible
4. Get the mappings right
5. Exploit the power of constraints, both natural and artificial
6. Design for error
7. When all else fails, standardize

[Norman (2002:188-189)]

2.2.3 Heuristic evaluation of user interface

Heuristic evaluation is an informal user evaluation method based on the existing running system or mock-ups thereof as specified by Nielsen & Molich [1990, Nielsen, 1992; 1993; 1994a]. Nielsen specifies a set of ten heuristics which a system should be tested for. The user-story (attachment 10) used in the test addressed all but the tenth criteria The ten criteria are:

1. Provide visibility of system status
2. Ensure match between system and the real world
3. Allow for user control and freedom
4. Be consistent and follow standards
5. Prevent errors
6. Utilise recognition rather than recall
7. Allow for flexibility and efficiency of use
8. Provide aesthetic and minimalist design
9. Help users recognise, diagnose and recover from errors
10. Provide help and documentation

[Hertzum & Jacobsen (2001:3)].

3. Development-project

The project that this paper is based on was the development of a user interface for controlling a bioreactor developed by North American company PBS Biotech Inc. The development project started out with reviewing existing bioreactor controller software on the market. After a comprehensive review it was clear most available tools would take quite an effort to customize and yet would still not represent what we wanted to achieve. They were simply too complicated to use and had not aged gracefully in comparison with the rapid development in the technology-field in recent years. As such, the team started to compile a list of the best attributes of each existing solution. Attachment one, two and three depict the interfaces of the controller-software that was studied. Interviews with users of existing software-solutions were made during which we tried to ascertain what elements users found complicated and the difference between the usage patterns of new users compared to those of experienced ones. One clear distinction was that all the tools presented a lot of information without concern for the context the user was in. The result was simply “information overload” obfuscating the user from performing certain tasks. Based on this input a few core principles for our user interface were established.

3.1 Principles of the Bioreactor-project

Experiences from interviews with users of existing software-solutions, established theory on human computer interaction and attributes of the actual machine all shaped the design considerations. Since the bioreactor in itself is novel in its construction, a greater tolerance for new approaches to established norms would be accepted. With this the team could embrace emerging technologies previously not utilized in systems of this kind such as distributed control-mechanisms and touch-interfaces. Five important considerations were laid as base for the prototyping-effort. These were:

- Amount of information that has to be communicated to the user is vast
- Security and reliability is key. This means the system should actively try to avoid letting the user make mistakes or letting the user feed or represent erroneous data to the back-end
- The user interface should feel fresh, attractive and communicate a sense of the cutting-edge technology the bioreactor-solution represents
- The user interface must communicate seriousness and professionalism.
- The user interface system should embrace modern ways of doing computing such as distributed control and touch interfaces

By having a few ground-rules we hoped to gain leverage from what peers before us has learned and to learn from others’ mistakes. These were a combination of Apples Guidelines, Normans seven principles and the gestalt laws.

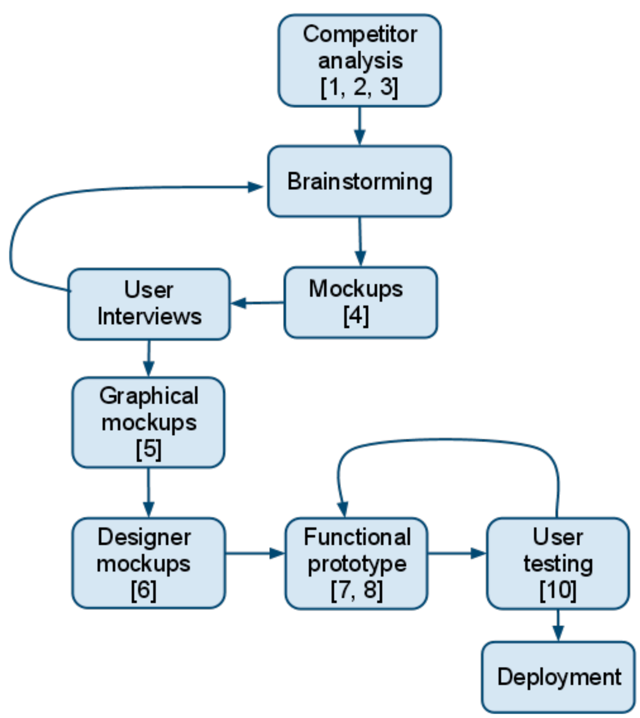
3.2 Design & Development

Because the information and data to be presented to the user was by our analysis determined to be highly context-related, a lot of effort went into identifying which contexts were present. With each possible context required information was identified and this shaped what was referred to as an “information group”. Using the group approach the design could more closely adhere to established theory on usability.

Less information with more relevance helps the user make correct actions and decisions. With input from interviews and a clear idea of the information grouping we set out to make plain mock-ups with no attempt to design, rather just to layout and try different scenarios. The mock-ups was based on identified tasks and paths a user takes through the system. When a user is trying to achieve X, which factors and what data is required to make an informed decision. By applying the 80%-rule found in the Apple Human Interface Guidelines, “designing your software to meet the needs of at least 80 percent of your users” [Apple Human Interface Guidelines, (2011:1-29)], more complex and particular tasks were placed in the background to make room and facilitate more common tasks. An example is present in attachment four.

Designing and testing the mock-ups internally and on potential users led to new insights and the mock-ups were updated accordingly in an iterative process until we had a result that seemed to meet most of the requirements. Next step in the development-process meant the team started to apply design. Main goal in that activity was to represent informational relevance by use of colours, position and sizes of text. An example of the output is found in attachment five. Parallel to this a back-end user interface was developed that allowed interaction with the machine as well as a way to test out the grouping of information. An example of this interface can be found in attachment 12.

During the design process, professional user interface designers were contracted to make an appealing and functional design proposal based on our early mock-ups. The result was several images displaying a virtual state of the machine in different modes and situations. Examples can be found in attachment six, seven and eight. This part also followed an iterative process and the team struggled with how to visualize anomalies in the machine without blocking or interfering with the user interface, preventing flow. Another important aspect was to give the user interface a sense of depth to further impress the feeling of an actual physical control-panel. The final result can be found in attachment seven and eight. Attachment eight show the machine in a modal state used when performing tasks that are changing the state of the sensors the machine uses to read. Modality is used when the actual input of sensors is irrelevant until a task is complete.



The finished designed mock-ups were then prototyped into a functional application that simulated functionality and behavior which allowed users to do interactive tests and comment. As certain areas started to see a decrease in user feedback, these became the first to be implemented in the final solution. The machine running the user interface can be found in attachment nine. A map of the overall development process can be found in this image where the numbers in brackets represents the attachment in this paper.

3.3 Problems

During the project a few problems emerged that were rectified as they were identified. However the impact of these problems has not been thoroughly investigated. These problems were:

- **Lack of use-cases -** Though a user centered system design process (USCD) was employed use-cases were never developed preceding implementation, leaving many critical task-oriented processes unclear. Therefore, we required several iterations of prototyping before a satisfying result was achieved. This also meant that there was no clear test-methods to ensure the system behaved as expected after each development iteration.

- **Lack of documentation -** No formal system-documentation preceded development, leading to low level of clarity regarding which technologies were employed, how the system architecture functioned and whether or not the deployment had been coupled with the specific resources in the company required for it to be successful.

4. Empirical studies

User testing is important to understand how successful the final product is to your targeted audience. User testing is not about testing your users but instead to have your users test your product [J.J. Garrett (2011:47)]. According to Butler a user's ability, or lack thereof, to accomplish certain tasks with the assistance of the system is an indicator of a systems' usability [Butler (1995:2)]. By recording or in other ways documenting a users interaction with the system and then performing analysis on the material, one can deduce how well a system is geared toward assisting a user to accomplish a task [Butler (1995:3)].

Identifying who the typical user will be, their aim and tasks as well as how they themselves perceive these tasks are pre-requisites for a good design-model. Thereafter it is the design-model that you measure and analyze to learn whether you have reached good usability [Butler (1995:6)]. The analysis has two goals. First to understand the situation as it is and the second goal is to identify how the situation can be improved [Butler (1995:7)].

The tests conducted made use of heuristic evaluation based on the ten principles laid out by Nielsen. Following the tests each test-subject answered a survey about their experience of the tests.

4.1 Personas

By establishing personas, a clear idea of the most common user was established. One persona was the focus of this study. The main persona is briefly described below:

> Persona 1 - 26 year old, has a masters in bio-chemistry and is doing an internship in a laboratory as assistant. Is familiar with computers and uses a laptop daily for work such as papers, reports and analyzing statistics. Has a stationary computer at home used primarily for social networking and mail. Has a iPhone and uses it exclusively personally and not for work.

Based on this persona, two groups of users were gathered. One group was bio-chemistry students whereas the other had no previous education in any topics related to biology but instead studied computer-science. These two groups allowed us to see if the interface design was predisposed to be more oriented towards people with a background in computer science rather than those with an understanding of bio-chemistry.

4.2 Test setup

The tests were performed over the course of five days at Malmö Högskola using four computer science students and four students from bio-medicine. A three litre bioreactor was installed and set up with 2.51l of medium, but without any cell-culture in Camarillo, California. The tests were conducted on a Apple Macbook Pro laptop running the Safari web-browser, which was connected to the bioreactor via a public wireless network connected to Internet.

The users were tested individually and the test followed a written script, found in attachment 10. The script put the user in a role-playing scenario where they followed the procedure of setting up a reactor for a new run, analogous to what the actual procedure in a laboratory is. The test-subject was monitored using user-behaviour tracking software called Silverback[5]. The test-subjects were presented with background information about PBS Biotech and the bioreactor and then the background of the test–scenario.

4.3 Talk aloud studies

Talk aloud studies (TA) are an established method in user testing. Usually the tests are done in groups of 4-5 test-subjects [Hertzum & Jacobsen (2001:3)]. In this study, the user-tests were monitored using video-recording software that tracked the users face and imposed this in a window on the actual screen the user was presented with. It also highlighted where the users clicked with the mouse. The users were asked to verbally communicate what they were doing, what outcome they expected to happen and how they were reasoning to come to these conclusions. During analysis of the studies, particular interest was paid to tasks where the user looked confused, surprised or happy as well as periods when they were moving the mouse around the screen in a seemingly random pattern without actually clicking anywhere.

4.4 Survey

All users were asked to complete an anonymous survey sent to them by email four days after they had done the usability-testing. The survey contained multiple-choice questions and aimed to give a demographic perspective on the users as well as learn more about their experience when testing the software. The survey in full can be found in attachment 11. The results of the survey were also used to better understand the recorded video of users interactions with the software. In addition, we asked about their previous experiences with user interfaces and how those experiences related to their success in working with the design. This could indicate whether the system had succeeded in simplifying bioreactor controls.

4.5 Reason for choice of method

By monitoring the users interaction with the system we could learn how the user reasoned when trying to identify and locate actions and tasks. We could also monitor how many erroneous steps they took in finding their way to target. Our desire was to see how the reasoning of a user not trained in the system differed from how we assumed they would interpret the design. By watching their reactions to alarms and system responses we could would learn whether the notification-system was as clear and intuitive as we intended it to be. The survey was used to better understand the recorded video of users interactions with the software as well as to get unbiased feedback on user-experiences.

[5] http://www.silverbackapp.com/ - 2011-05-22

4.6 Critical evaluation of method

As with all tests it is practically impossible to eliminate all weaknesses or external factors affecting the results. To avoid being mislead by conclusions it is imperative to identify risks and weaknesses in how the tests are performed. Our tests identified four areas that needs to be considered when analyzing the results.

1. Since all users participating in testing had no or little previous experience in working with commercial bioreactors some basic training in terms of establishing concepts and method had to be done. This also meant that the testing could not be completely autonomous but partly assisted by the test-supervisor. This might have impact in the end-results in how efficient the users identified certain parts of the system. Actions to curb the potential impact was taken by following a strict manuscript throughout the actual testing and remarks was made in test-protocol when any additional information was added outside of the manuscript.

2. The manuscript found in attachment 10 which contains the tasks the user was performing was written by the test-supervisor and is deliberately designed to test certain areas of interest. It is possible that this has an impact on the results. A more thorough test would have a second test-manuscript developed by an impartial test-supervisor. Another way to curb this would be to measure the evaluator effect by having several test supervisors conducting their own test and then comparing the results per problem according to a algorithm such as the one presented in "The evaluator effect", based on an average of problems found per evaluator per area [Hertzum & Jacobsen (2001:4)].

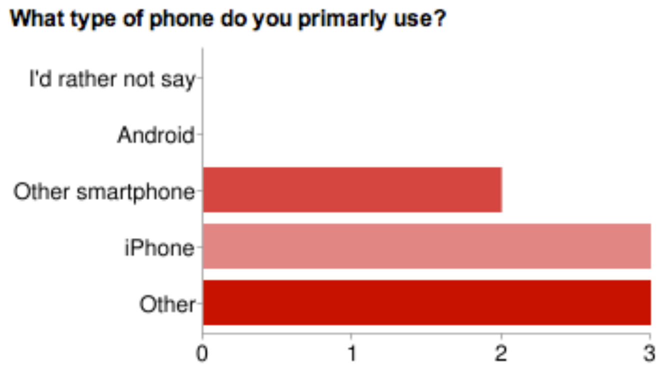
3. It is an unlikely that a user would ever interact with a bioreactor system without first having formal training in the software and a good understanding of the fundamentals of bio-chemistry. As such the users participating in the test were not realistic. This however was a deliberate decision taken in order to develop an unbiased view into the suitability of the user-interface for the targeted persona by comparing results from a slightly different user-group.

4. The user interface is designed to be easy to learn. However, due to the lack of informative texts and a notification-system, first time use could be puzzling, and is not representative of normal user conditions. A more thorough test would have the same script used in an additional test to see how well acquainted the users become during a second use of the software.

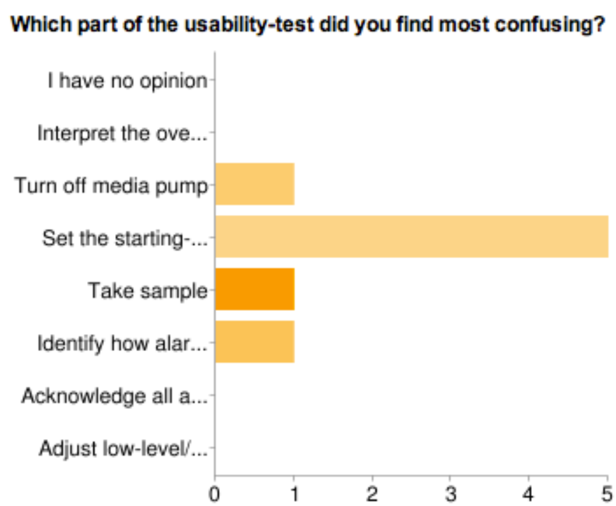
5. Results

Due to the nature of the recorded screen-sessions the resulting data is observations presented here.

The test-subjects were divided in terms of previous computer literacy and 62.5% had smart-phones whereas the other did not. The test-subjects previous experience with smart-phones did not seem to influence proficiency with navigation in the user interface. Instead, both groups appeared to be at an even level in terms of performing basic functions, based on number of detours and time to target-measurements. The time from test initiation until when the users started to click on objects in the user-interface showed that the more computer-literate the users were, the quicker they felt comfortable testing interactions out with the system.



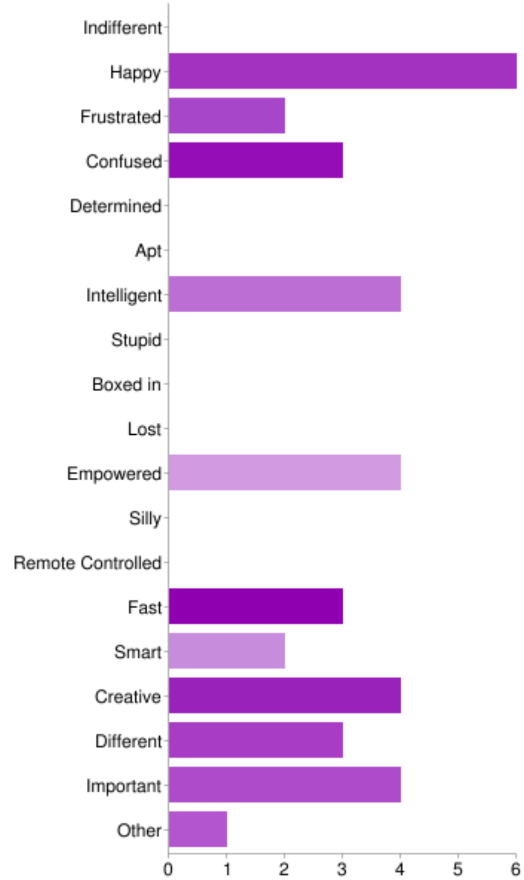
When asked to start configuring set-points, it took the users an average of 12 seconds to identify that the part of the dashboard-panel where sensor-values are displayed also served as buttons. Once this relationship was established, they never had any problem locating tasks that were related to setpoint-data. All of the users identified the relationship between current value of each sensor and the corresponding trend-lines on the dashboard. The visual representation meant to indicate which mode the user has set the bioreactor's sensor to did not make sense to 80% of the users when they were asked what the icon represented. They identified a relationship between the changed state of icons and their actions, but failed to explain the relationship accurately. All test-subjects had problems identifying the manual entry-mode for adjusting the gas-mix. When the users failed to quickly locate where a task was initiated they felt concerned and after only a short while showed signs of frustration.



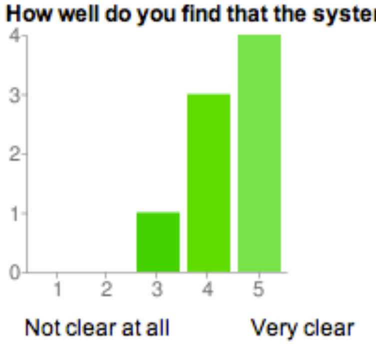
Though frustration was expressed by 62.5% of the users when locating manual entry-mode for gas-mix, all users responded positively when asked about the overall emotions experienced while using the system. 75% expressed that they felt happy when using the system and other emotions frequently cited were feelings of intelligence and creativity. “Confused” was an attribute that also ranked high. The users with less experience in bio-chemistry were more likely to attribute the system with making them feel happy, whereas the bio-chemistry users all stated feeling intelligent as being leading attribute.

All users took note when the machine raised alarms as well as when the machine-alarm was automatically corrected and un-flagged. All users found that the system’s way of indicating alarms was easy to understand and raised their attention without creating the feeling that the user personally had made an error. When asked control-questions about the state of the machine all users managed to quickly interpret the information presented by the interface and provide an accurate answer.

How did the Hello-software make you feel as a user?

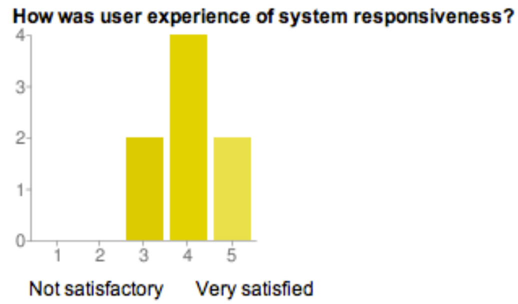


How well do you find that the system communicates information based on the importance of said information?

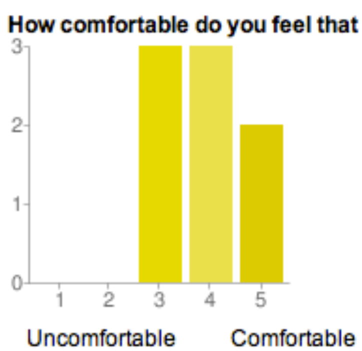


1 -	Not clear at all	0	0%
2		0	0%
3		1	13%
4		3	38%
5 -	Very clear	4	50%

The users quickly found their way around the system and seemed comfortable interacting with it. The lag that occurred due to the fact that the machine in California was remote controlled from Sweden caused minor disturbances in signalling to the user whether actions had been saved or were properly processed. One user expressed concern with the lack of immediate response however managed to complete the task assigned. One part of the system, namely "Calibration" was tested with overall poor results. The users failed to recognize that the machine had received their input, nor did they notice the system's response to interactions. This made the steps required to complete the tasks confusing and all users needed assistance from the test-supervisor to complete this action. The survey however did not indicate that this was experienced as a problem to the users.



The survey asked specific questions regarding the look and feel of the user interface and users assigned high grades with regards to visual appeal. They also expressed feeling comfortable with the interface and showed high average ranking in terms of trust for the system.



1 - Uncomfortable	**0**	0%
2	**0**	0%
3	**3**	38%
4	**3**	38%
5 - Comfortable	**2**	25%

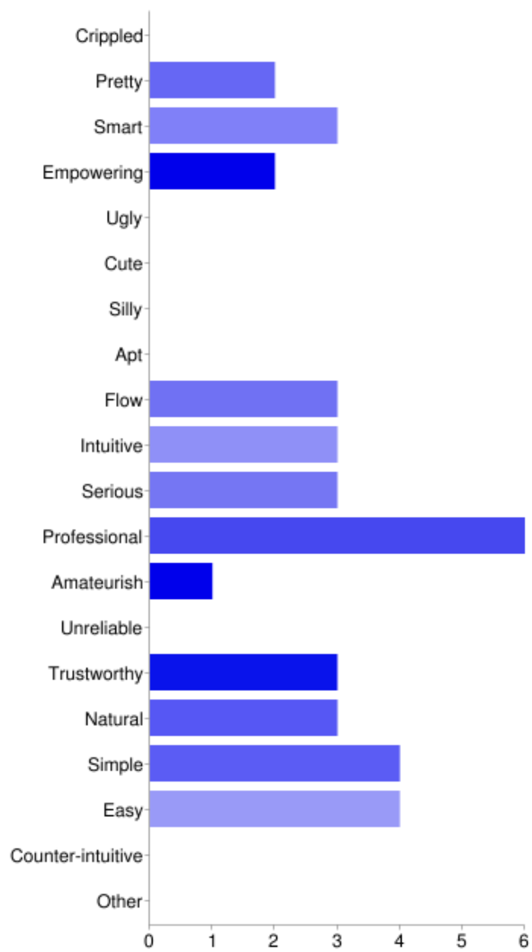
On the question related to whether the test-subjects found the user interface satisfactory, if the location of items and tasks felt logical and seemed to make sense, the users generally gave high rankings. The recorded video show that all users quickly learned to identify most items. However, some elements – such as alarm ranges and gas mix properties – required a great deal of searching for all users.

Did you feel that your preferred actions was easy to locate in the user interface?

1 - Not satisfactory	**0**	0%
2	**0**	0%
3	**3**	38%
4	**4**	50%
5 - Very satisfied	**1**	13%

When asked to describe the user interface using a select group of words that were deemed relevant, the users chose words such as "flow" and "trustworthy".

Which words best describe the Hello Software?



5.1 Analysis and discussion

The project set out to re-invent how user interfaces for controlling bioreactors are made using state of the art technology and established theory in human computer interaction. Early on in the project five criteria were established. First, although system information is vast, it has to be communicated in an informative way and aid rather than confuse the user. Reliability of the system was important: the user should never assume that the machine is doing something different from what was intended and if there is a problem it is imperative that the user interface succeeds in communicating this to the user. The user interface should be easy to navigate, feel modern and professional. Finally the system should support touch-interactions and be distributed. By following Normans' principles, Apple's guidelines and by adhering to established theory about mental models and how users consume information in a user interface, the intention was that the user should feel comfortable and enjoy the system, and that this would lead to less mistakes and to users performing their tasks more efficiently.

Given that the users started interacting with the user interface immediately, and supported by high rankings in the follow-up survey, it is understood that the user interface is inviting, attractive and provides an interactivity-model close to the users mental model. The users approached the system by clicking on elements, text and buttons in order to explore the effect, while showing little concern about whether something could break or not. The user interface did not seem to intimidate the users and a sense of curiosity drove their actions in the right direction. They seldom performed the wrong action while convinced they had chosen the right one, indicating that although certain actions were hard to locate, the users never mistook one action for another. This suggests that users were unlikely to make errors stemming from confusing or ambiguous interface design elements.

The success-rate and average time spent on each task were very similar in both user-groups tested, meaning that the user interface manage to transcend the nomenclature of the tasks it was designed to perform. Even for test subjects untrained in bio-chemistry, the system assisted the user with tasks to such a degree that they succeeded without necessarily understanding the inner bio-technical workings of the actions they had just performed. This was further evidenced by survey results which showed that the more computer-proficiency the user had, the happier they felt with the user interface, whereas bio-chemistry trained users had a stronger sense of feeling intelligent and empowered when using the interface. These results are likely related to the attractive and modern look and feel of the interface, but also indicate that the users mental model is aligned with the user interface design. The information is clearly understood, relevant to the tasks the user is trying to perform and presented in an attractive way.

The users previous experience with smart-phones did not seem to influence proficiency with navigation in the user interface. Instead, both groups appeared to be at an even level in terms of performing basic functions, based on number of detours and time to target-measurements. The users equipped with smart-phones seemed to have an easier time understanding the four categories that make the application's function-groups, whereas the other test-subjects expressed confusion between the division of "Action" and "Setting" functions. This led to them always browse the settings-panel before being assured that the proper function was in the "Actions"-tab. All test-subjects had problems identifying the manual entry-mode for adjusting the gas-mix. When the users failed to quickly locate where a task was initiated they felt concerned and after only a short while showed signs of frustration. The spread over gender indicated no difference in emotions. The users with less experience in bio-chemistry were more likely to attribute the system with making them feel happy, whereas the bio-chemistry users all stated feeling intelligent as being leading attribute.

Overall, the users claimed in the survey that the user interface felt responsive – but the recorded videos show several instances where the users were left waiting for visual indications or cues from the system. Measuring lag times in the testing shows us that if the system failed to respond within approximately 400ms, the lag registered with the user, who then started to look around for some explanation as to what was “wrong”. This is interesting to note, as the user commonly assumed something was broken when visual indicators were delayed, even though the user was aware that the machine was located half-way around the world. When the system responded within around 200ms, the user did not seem to take note, suggesting they felt the reaction of the system was sufficiently “immediate”. Users seemed more comfortable when they had an immediate response to their actions. This response to lag is important to consider, as the system was designed in part with the intention that users would assume things were functioning correctly unless the interface visually communicated that something was wrong and clearly this was not intuitive to the users.

The users all took note of raised alarms indicates that the way the system communicates anomalies is intuitive and distinguishes itself enough from the rest of the user interface to clearly mark these communications as exceptional. The fact that alarms did not intimidate or interrupt users, nor make them nervous or confused indicates that the level of severity is appropriately communicated in visual design. All users took note of the situation, reasoned why it appeared and calmly addressed the alarm with appropriate actions. The choice of alarm colour and location as well as the choice to use visual indicators without audible notification were important ones to test, as these choices were suspected to represent the minimum notification needed to clearly register with the user. The theories that provided a foundation for the work with the user interface were closely studied with regards to how errors and discrepancies should be communicated and it was interesting to see the successful outcome of this careful application of theory.

The fact that the user interface always presents a window to the actual machine-state could sometimes have the unintuitive effect of contradicting what the user was telling the system to do. If the user turned on a pump but for some reason the machine failed to accommodate this action, the user interface communicated this by showing the pump going from a temporary state of “On” back to “Off”, leaving the user to acknowledge that the pump in fact did not turn on. The tests showed that this behaviour baffled the users at first but quickly became a model that they felt comfortable with. The talk aloud tests indicated that the user had an increased sense of trust with regards to the accuracy of the user interface after learning this behaviour of current state visualization.

The attributes that users in the survey selected to describe the user interface following the test highlighted several words that were key in the inception of the design-project. These words were chosen in contrast to their counter-parts in the list of available keywords. Namely, that most users felt the word “flow” described the software was of particular interest to see, but also that “simple” and “easy” were attributes almost all users chose. One user expressed the characteristic “amateurish” to describe the software but also expressed “trustworthy” and “empowering” and indicated that a feeling of being important was experienced when using the software.

The tests showed no difference in success-rates with the user interface due to gender but seem to indicate different ways of learning how to interact with the system. Female test-subjects tended to rely more on visual cues and used fewer clicks to find each target-action but expressed a greater uncertainty before executing operations. Often, they spent a longer time on each screen before confirming a change or action and think aloud tests showed that they tried to second-guess themselves, questioning whether the action would work. Male test-subjects showed a greater need to accumulate as much information as possible surrounding the task they tried to perform, but once they had clicked around and assured themselves with regards to what the proper actions was, they never appeared to stop and second-guess or think the action through. Whether gender should have been a more important characteristic in the development of persona or whether the apparent difference in learning and use patterns is a negligible phenomenon which might be rendered insignificant in actual user-training is outside the scope of this paper to address. The level of experienced uncertainty was also expressed in where test-subjects positioned the mouse when clicking on confirm-buttons. The more uncertainty they felt, the nearer the edge they would click, whereas they clicked in the center of buttons when they felt confident in the action they were taking.

6. Conclusion

To what degree can one say the user interface is successful as a result of closely following theory in usability and human computer interaction? Is the user more comfortable because of the use of a select few design guidelines and is the use of colours and sizes important to make a understandable user interface? These are the questions this paper set out to answer.

The users had no previous training in the user interface nor much in bio-chemistry and yet managed to complete several advanced tasks required to run a bio-reactor in tests based on a real-life scenario. They controlled an actual reactor and though mistakes were made, nothing was damaged nor did they fail to accomplish any of the tasks. They finished tasks rapidly and according to their feedback, they had a good time performing them. Therefore, it is my conclusion that the user interface is a success.

The font-sizes and colors used to represent information, chosen based on their relevance to the operational context, led the users to quickly understand and accordingly respond to the machines running-state during testing. As such it is my conclusion that the use of contrasting colours and varying sizes played an important role in the success of the user interface.

The success of the user interface should be attributed to our careful adherence to the guidelines and principles used in the development-process.

6.1 Recommendation

As a result of this papers conclusion it is my recommendation that usability-testing become an ongoing development-task during the continuation of the project.

As a result of the usability tests it is my recommendation that the user interface embeds more active feedback between the user interface and the user when the client is waiting for server response that could exceed 300ms.

7. References / literature

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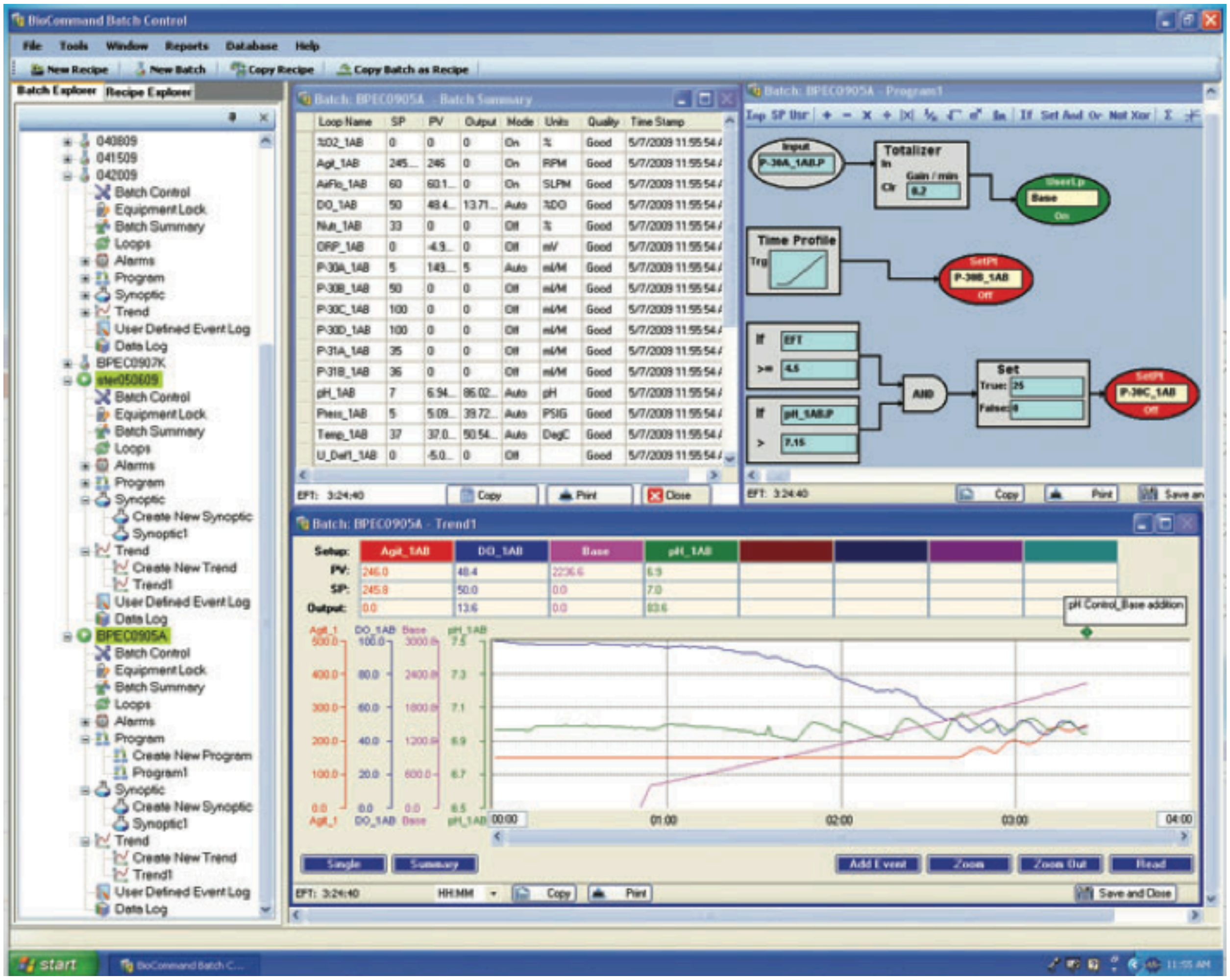
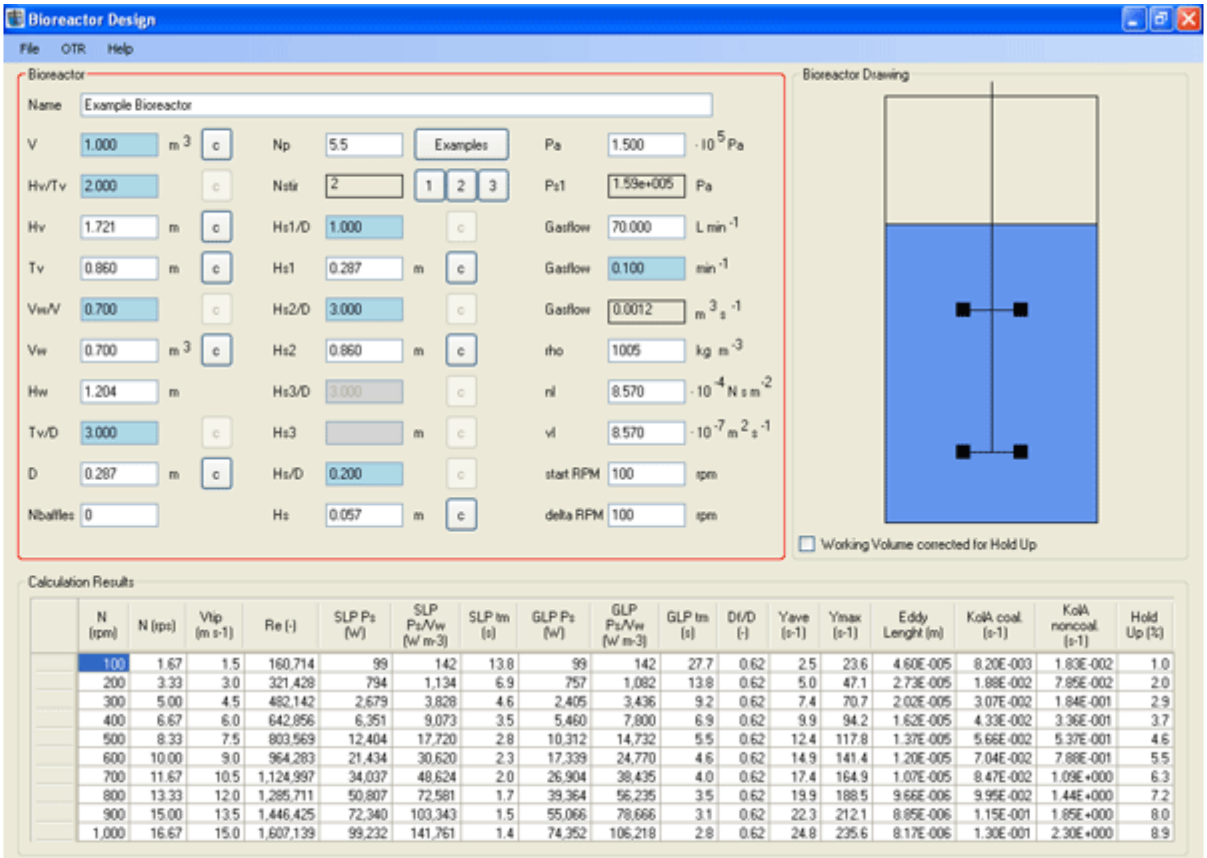
8. Attachments

8.1 Attachment 1



One competitors product for monitoring and controlling a bioreactor. Used in planning

8.2 Attachment 2

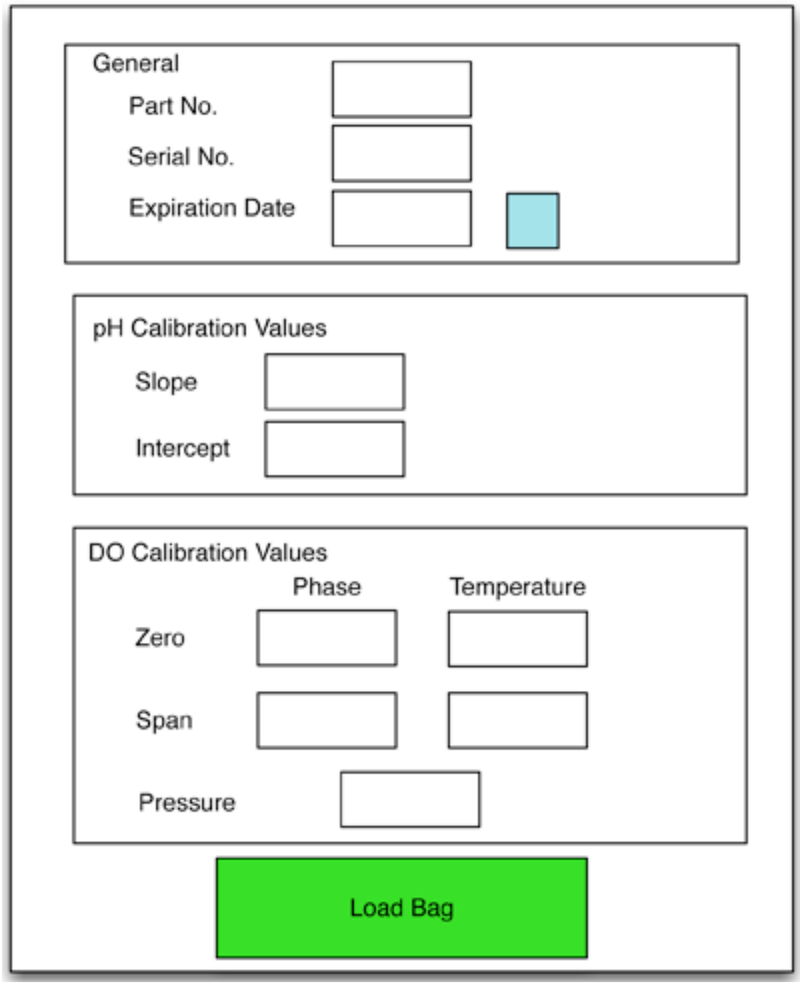


A second competitors system considered to be user-friendly. Used in planning

8.3 Attachment 3

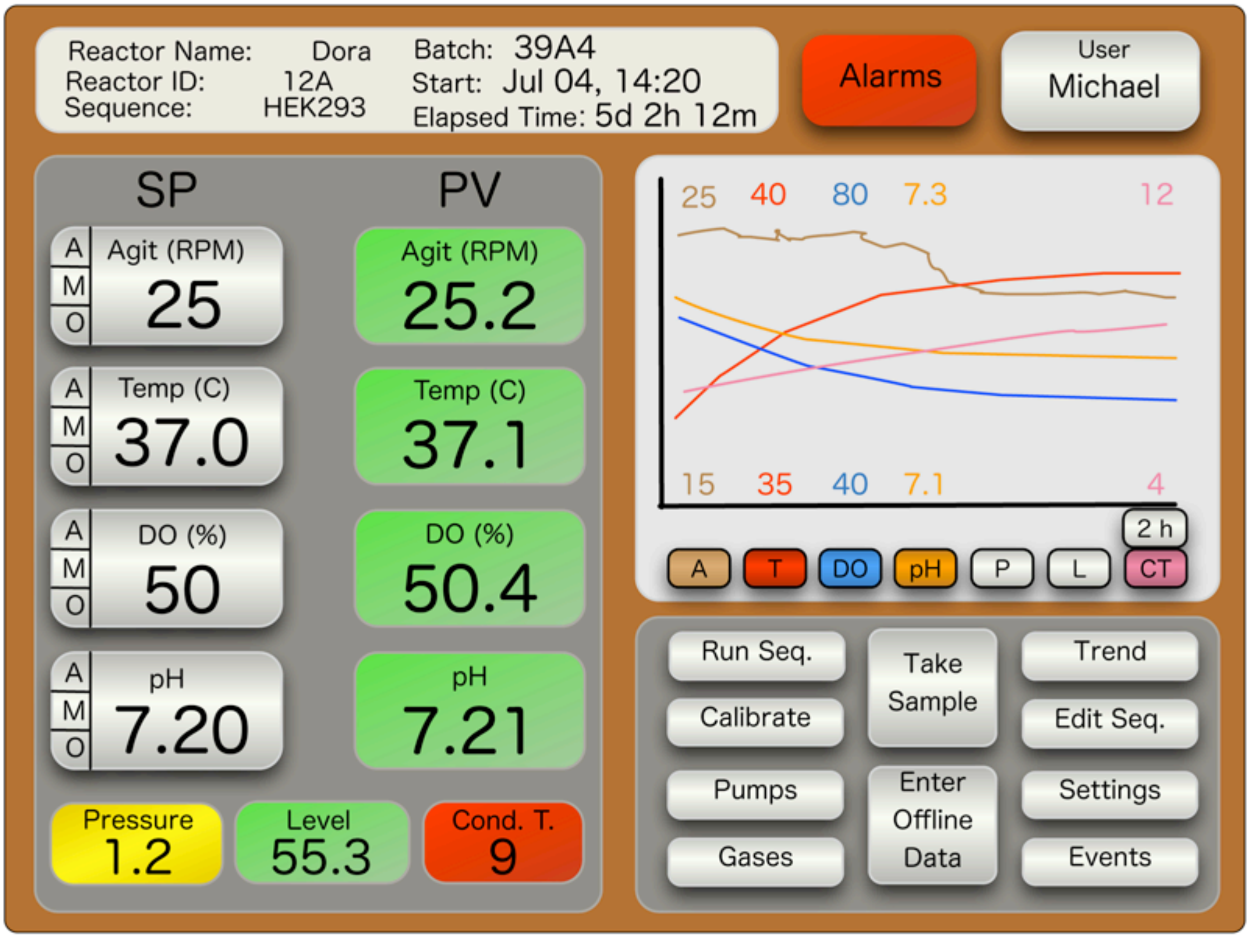
A third competitors software solution for bioreactors on the market today. Used in planning

8.4 Attachment 4



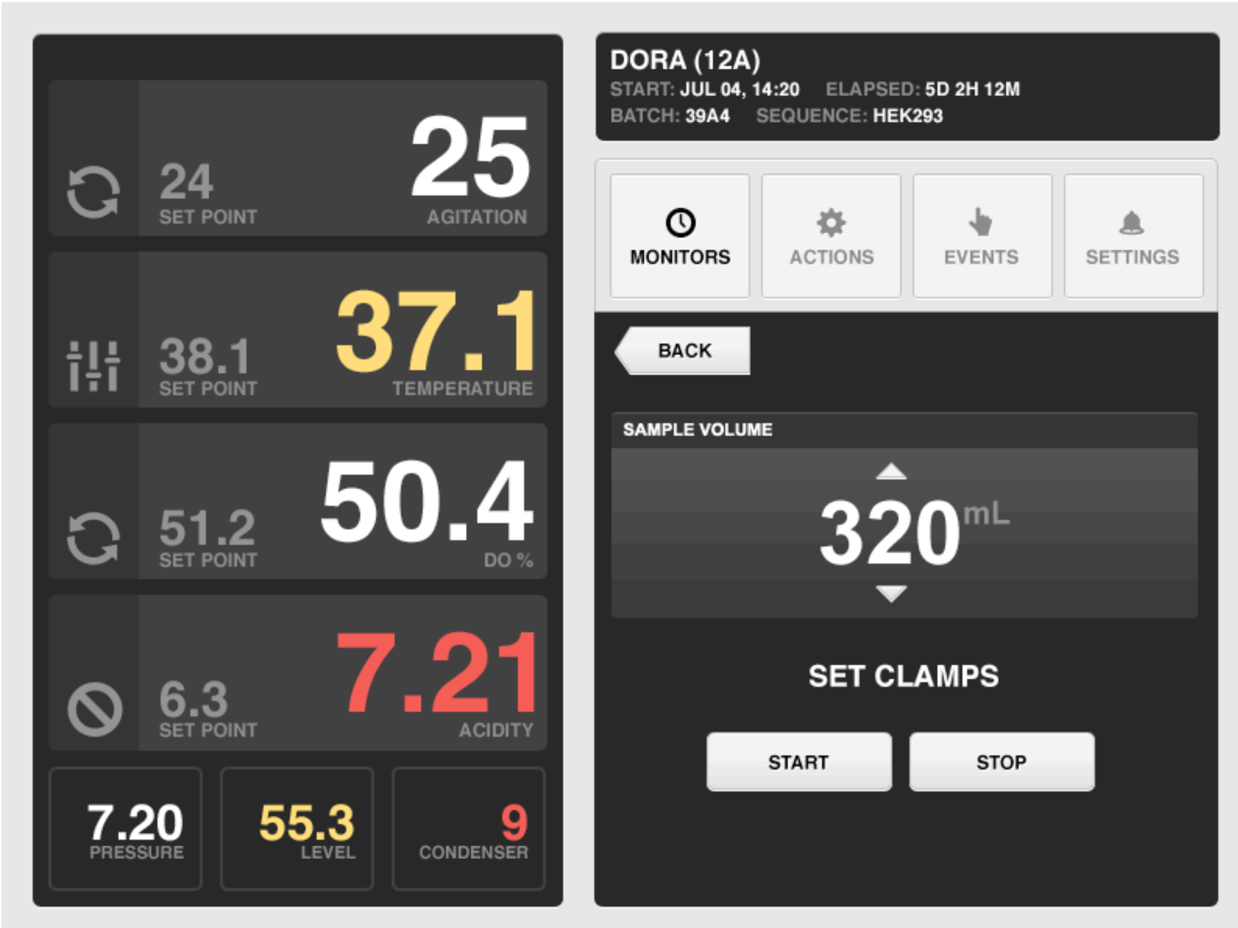
One of the early mockups to test information grouping and prioritization

8.5 Attachment 5



First graphical mockup that was tested and then sent to designers

8.6 Attachment 6

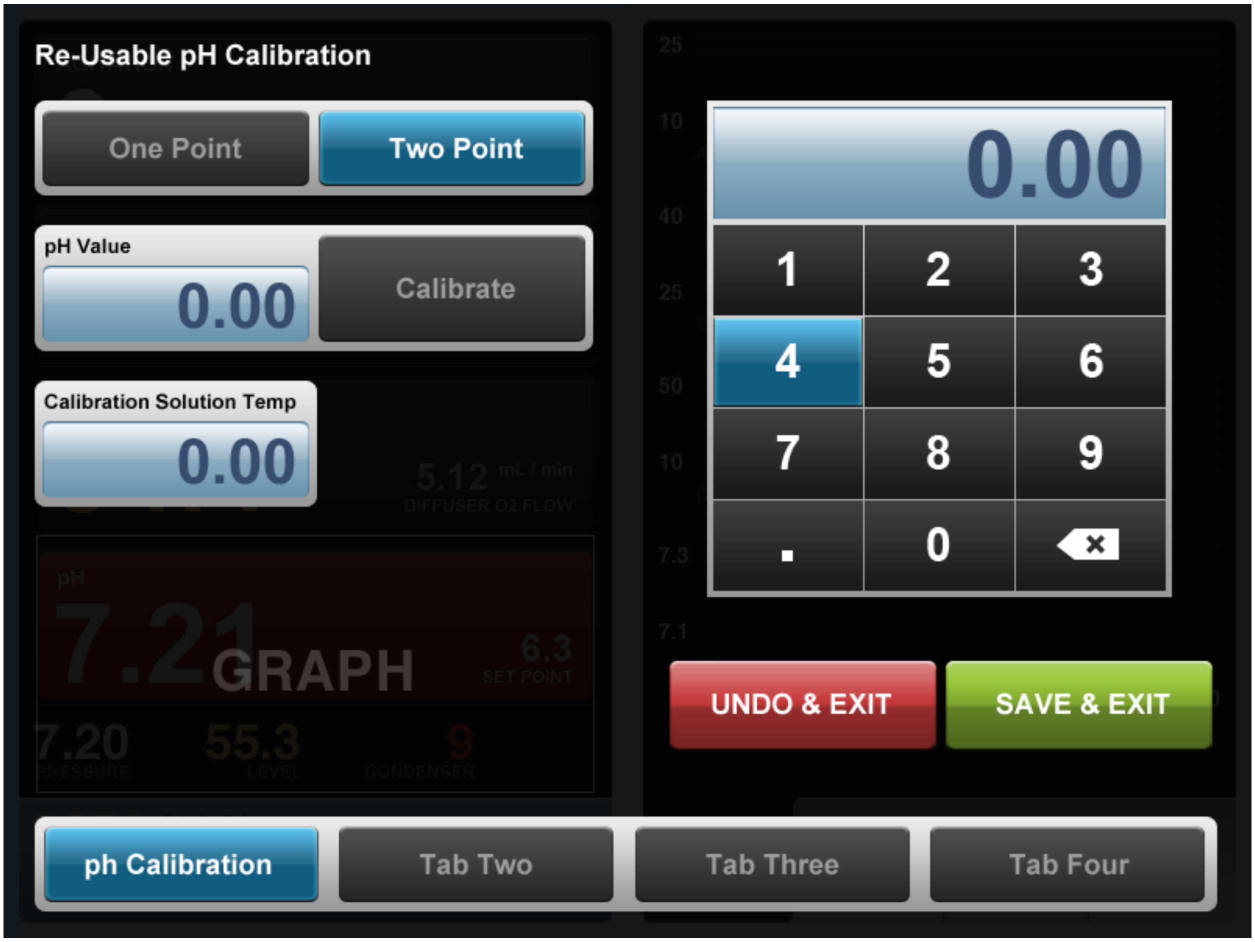


First prototype tested on users for interaction and information review

8.7 Attachment 7

Second tested prototype, currently the one being used in testing

8.8 Attachment 8



Second type of interactive surface in the application, modal display

8.9 Attachment 9

The bioreactor in question running a batch with the user interface

8.10 Attachment 10

Use Test Case Scenario:

Your aim is to verify and configure a 3L bioreactor for a start of a fresh batch. This includes several tasks and your objective is to identify required actions to complete each task described by the test supervisor.

As you start the test a new bag has been placed in the bioreactor and is being filled with medium. Since the bag is now full we need to turn off the pump responsible for filling the bag with medium.

- Please turn off the media pump

Your first objective now is to equilibrate culture to starting conditions and inoculate with cells.

- Please equilibrate culture to starting conditions, these are:

Agitation = 25 rpm
Temp = 37.0 deg
7.0% CO2 in the gas mix
DO = 50% Air Saturation.

When you have set starting conditions you need to ensure that the sensors are reading values correctly by doing a manual control of the values and compare to the values indicated by the instrument. To do this you must get a sample of the medium. A syringe is attached to the bioreactor ready for a sample to be extracted.

- Please find a way to start extraction of a sample into the syringe

When you do your offline measurement you read that pH is 7.22 and DO is 102%. This mean that the sensors are slightly off and need to be calibrated against this offset.

- Please find a way to perform calibration of pH and DO as to adjust to -your offline measured value

Since the bioreactor was in startup-mode all values were out of range, triggering alarms that now should go away as the instrument come into the correct ranges with the applied values.

- Question: How is this indicated?

The machine is alerting you to the fact that range-alarms has occurred at a previous point in time.

- Question: How is this indicated?

- Please find a way to acknowledge all previous alarms and take note that no new alarms are present when complete

When monitoring the run for a bit you can tell that values are within range.

- Question: How is this indicated?

You decide that the alarm for Agitation is set to low and you need it to be more defensive in reporting alarm when out of range. This can be configured as a setting.

- Please find the setting-panel to adjust the low-level RPM for agitation and set it to 10

You feel confident that the run is stable enough to leave unattended but want to indicate to others in the lab that a batch is running by turning on the light in the bioreactor.

- Please turn on the main light in the instrument

8.11 Attachment 11

PBS Biotech User Experience Survey

This survey is supposed to take about five minutes and presumes you have taken part of PBS Biotech training, worked with the bioreactor or participated in usability training.

* Required

Demographic information

Gender *

- I'd rather not say
- Female
- Male

What is your age?

I'd rather not say

What type of phone do you primarily use?

(this is to get an understanding of your comfortability with mobile user interfaces)

I'd rather not say

What computer and OS do you use?

I'd rather not say

How would you determine your computer proficency?

(Are you apt user of computers and feel comfortable with different computers and operative systems)

	1	2	3	4	5	
Litte experience	○	○	○	○	○	Very experienced

How familiar are you with bioreactors since before?

(2-3 you have studied the topic or have in-depth knowledge in the chemistry of bioreactors, 4- you have had hands-on experience with bioreactors)

	1	2	3	4	5	
No experience	○	○	○	○	○	Very experienced

How well acquainted do you feel with the topics of bio-chemistry?

	1	2	3	4	5	
Not at all	○	○	○	○	○	Very acquainted

Hello Software

Hello is the name of the software you used to control the bioreactor. This is the software in question for this survey and usability-test

Did the user-story and the actions you were asked to perform make sense?
(Did you feel like the actions were out of the blue or did you understand them and what they asked of you?)

	1	2	3	4	5	
No sense	○	○	○	○	○	Very clear

How was your experience of the user interface layout?
(colors, buttons, proportions, visual appeal)

	1	2	3	4	5	
Not satisfactory	○	○	○	○	○	Very satisfied

How was user experience of system responsiveness?
(Did you feel that the system felt snappy and responsive to your actions)

	1	2	3	4	5	
Not satisfactory	○	○	○	○	○	Very satisfied

Did you feel that your preferred actions was easy to locate in the user interface?
(Do you feel like it is a "long way" to find your requested button)

	1	2	3	4	5	
Not satisfactory	○	○	○	○	○	Very satisfied

How did the Hello-software make you feel as a user?
(The software that you used to control the bioreactor is called Hello. What emotions do you best tie to the experience, check as many as you feel apply)

- ☐ Indifferent
- ☐ Happy
- ☐ Frustrated
- ☐ Confused
- ☐ Determined
- ☐ Apt
- ☐ Intelligent
- ☐ Stupid
- ☐ Boxed in
- ☐ Lost
- ☐ Empowered

- [ ] Silly
- [ ] Remote Controlled
- [ ] Fast
- [ ] Smart
- [ ] Creative
- [ ] Different
- [ ] Important
- [ ] Other: ______

Which words best describe the Hello Software?
(Which characteristics best describe your idea of the software?)

- [ ] Crippled
- [ ] Pretty
- [ ] Smart
- [ ] Empowering
- [ ] Ugly
- [ ] Cute
- [ ] Silly
- [ ] Apt
- [ ] Flow
- [ ] Intuitive
- [ ] Serious
- [ ] Professional
- [ ] Amateurish
- [ ] Unreliable
- [ ] Trustworthy
- [ ] Natural
- [ ] Simple
- [ ] Easy
- [ ] Counter-intuitive
- [ ] Other: ______

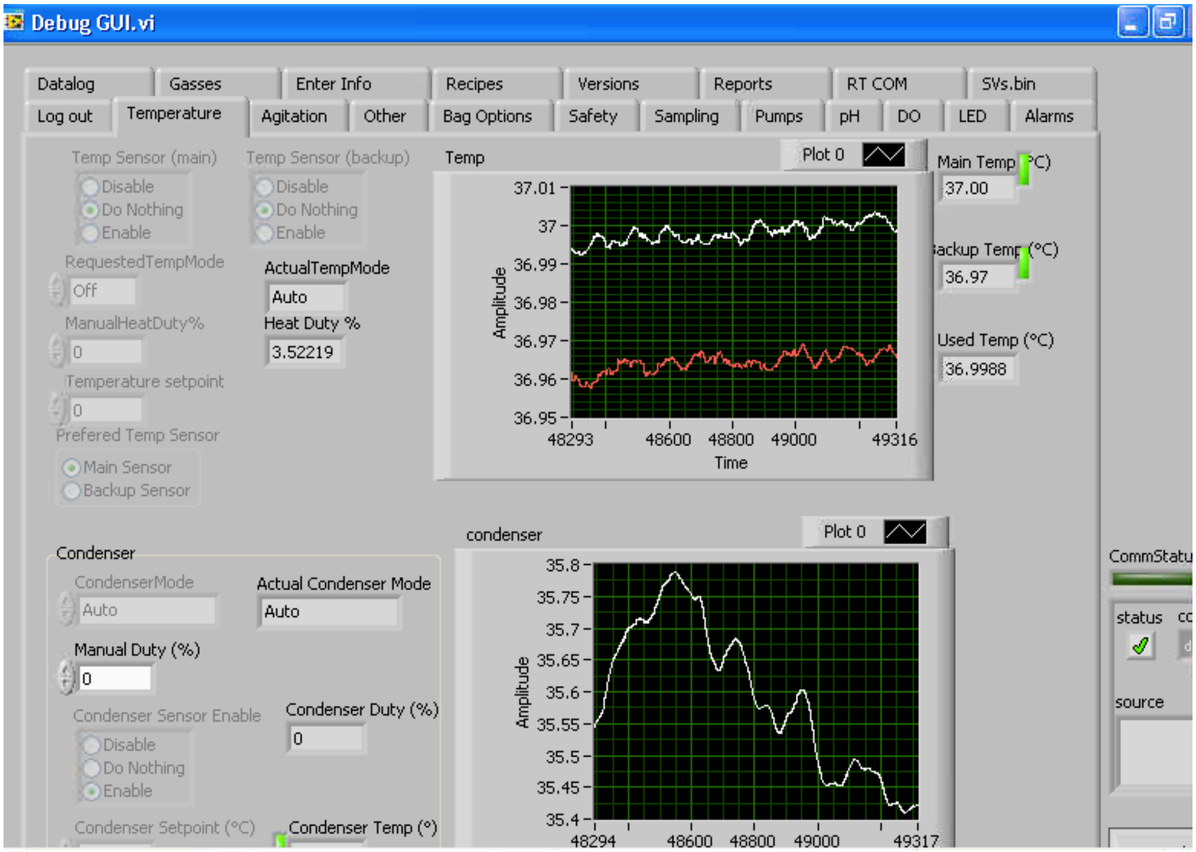
Which part of the usability-test did you find most confusing?
(Confusing from a usability point-of-view, not confusing due to lack of previous experience of bio-chemistry)

I have no opinion

Which part of the usability-test did you find make most sense?
(Makes sense as in easy and logical from a usability point-of-view, not easy due to previous experience of bio-chemistry)

I have no opinion

8.12 Attachment 12



The backend user interface