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I, Xin Lei, hereby submit this original work as part of the requirements for the degree of Master of Design in Design.

It is entitled:
Analyzing “Design + Medical” Collaboration Using Participatory Action Research (PAR): A Case Study of the Oxygen Saturation Data Display Project at Cincinnati Children’s Hospital Medical Center

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Analyzing “Design + Medical” Collaboration Using Participatory Action Research (PAR):
A Case Study of the Oxygen Saturation Data Display Project at Cincinnati Children’s Hospital Medical Center

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Master of Design

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Abstract

Collaboration between “Design” and “Medicine” is in need in the era of expanding specialization. Biomedical Informatics (BMI), as an emerging field within medicine, plays an important role in health care process. On the one hand, BMI will benefit from the innovation of designers. On the other hand, BMI can be challenging for designers because of its increasing complexity. How can a designer participate in BMI effectively, and what are the obstacles that designer needs to overcome?

Conducted by Cincinnati Children’s Hospital Medical Center, the SpO2 data display project provides a great opportunity for a designer to participate in and reflect insights along the research and design process. Participatory Action Research (PAR) is selected as the method for the designer to plan, act, observe and reflect. Insights about designer’s feelings, research process and clinical knowledge, and also the relationship between these insights and design solutions, are analyzed.

Key words:

Design, research, collaboration, biomedical informatics, PAR
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1. Introduction

The expansion of specialization has been a contraction of innovation needed to meet systemic problems. Research funding agencies are calling for greater levels of collaboration across disciplines in the sciences in general, and medicine in particular (Zender, 2011). The Mayo Clinic formed the Center for Innovation to integrate design into medicine with the goal to facilitate changes (Smith, 2010). These opportunities for successful user-centered innovations in healthcare exist not only within US but also in other cultures e.g. Japan (Taisuke Uehira, 2009).

Biomedical informatics (BMI) is the science of information as applied to or studied in the context of biomedicine (Elmer V. Bernstam, 2010). It is an important field of medicine and healthcare because gathering data and interpreting their meaning are central to the health care process (Edward H. Shortliffe, 2014). Studies also show that harnessing the power of information technology to improve health status both of individuals and of populations is claiming unprecedented attention nationally and internationally (Prudence W. Dalrymple, 2011).

Although biomedical informatics has been an “emerging field” for decades (Elmer V. Bernstam, 2011), with inherent properties of complexity, intricacy and large amount of information, BMI is not a exception as part of the health care system, which is a system “slow to understand information technology, slow to exploit it for its unique practical and strategic functionalities, slow to incorporate it
effectively into the work environment, and slow to understand its strategic importance and its resulting need for investment and commitment” (Edward H. Shortliffe 2014). At the meanwhile, the focus on creating innovation is the strength of designers, which can properly compensate for the downside of medicine (Zender, in press). With such a big need for creative solutions of improvement, “Design + Medical” collaboration is prospective and productive in improving existing biomedical informatics.

However, as biomedical technology is getting increasingly sophisticated (Helmer KG, 2011), biomedical informatics projects can be challenging for designers. Designers are rarely medical professionals, so they need to be brought up to speed with medical knowledge specific to the problem at hand (Zender, 2014). Improving BMI system is not only about making it “look better”—a real meaningful design solution should simplify user flow, provide clear information and improve communication efficiency, with the original function the same or even better. All of these come from a thorough understanding of the medical context and user flow, which need a great deal of research and user study within certain medical staff. How can a designer get involved in the medical research and design process more effectively? What should a designer do to overcome both knowledge and attitude obstacles, then contribute to BMI research activities?

In order to answer the questions above, it will be valuable and useful to have an empathetic story, case or reference about what does a designer do, what does a designer think and how does a designer feel when participating in a specific BMI design projects, and how those insights through the whole design
process of a BMI project contribute to the design solutions. We’d like to see that from the start of a user study to the end of production testing, how a designer locate himself/herself correctly in a position where they can create a project containing value. Therefore, a design project or case in BMI where the designer is involved from the beginning, will be a perfect starting point for collecting this kind of data and will generate useful insights.

Conducted by Cincinnati Children’s Hospital Medical Center, the project of oxygen saturation (SpO2) data display, of which the goal is to employ user-centered design methodology to develop data displays that inform decision-making in supplemental oxygen delivery and test the feasibility of data displays in clinical practice (Dr. Patrick W. Brady & Heather C. Kaplan), is an opportunity to capture the impact of designer involvement from the beginning- a rare yet valuable occurrence and precedent for future designers. Lots of design phases are covered in this SpO2 project. For example, the research team (including me) observed nurses, who are the users, during their work and identified challenges or opportunities. We also had interviews with nurses to ask for their opinions about Epic system, baby-caring procedures, etc. After on-site observations and interviews, we synthesized all observation notes, and then consolidated them into a whole interconnected network so we had a better understanding of the large perspective. Then workshops were organized with nurses, and feedback of our user journey map and data display design concepts were collected.

In order to generate useful insights from the research and design process, a reflective process is useful.
Designer should not only concern about the engagement in this SpO2 design research project, but also need to be self-aware of his/her role in the reflective process, which means that he/she is not only participating in research and creating design solutions, but also observing himself/herself during the whole design process, so valuable insights can be recognized. As a method about “changing and improving” but not “creating”, Participatory Action Research (PAR) fits in the context perfectly, which is a methodology that seeks to understand the existing service, product, or situation by trying to change it, with the cooperation with reflection. Kemmis and McTaggart (2000: 564) proposed a spiral model of action research, although the authors do not recommend that this is used as a rigid structure. They maintain that in reality the process may not be as neat as the spiral of self-contained cycles of planning, acting and observing, and reflecting suggests. Studying the PAR model helps me understand how to apply this method to my reflective study on SpO2 project. After relevant study and analysis, I selected PAR as a method to conclude insights based on my experience and involvement within the specific SpO2 project. With detailed notes of what I’ve done, what I’ve been thinking and what I’ve felt confused about, I will be able to synthesize them and come up with a series of usable and practical insights and then analyze how these insights can influence design solutions.

2. Methodology: Participatory Action Research

Participatory action research (PAR) is an approach to research in communities that emphasizes participation and action. It seeks to understand the world by trying to change it, collaboratively and
following reflection. PAR emphasizes collective inquiry and experimentation grounded in experience and social history. Within a PAR process, “communities of inquiry and action evolve and address questions and issues that are significant for those who participate as co-researchers” (Reason and Bradbury, 2008, p. 1). PAR is commonly used for improving conditions and practices in a range of healthcare environments (Lingard et al., 2008; Whitehead et al., 2003).

With the purpose to learn through action that then leads on to personal or professional development (Koshy et al.), PAR involves a spiral of self-reflective cycles of (illustrated in Figure 1):

• Planning a change.
• Acting and observing the process and consequences of the change.
• Reflecting on these processes and consequences and then re-planning.
• Acting and observing.
• Reflecting.
• And so on ...

(Kemmis and McTaggart (2000: 595))
According to Kemmis and McTaggart, the process in reality might not be as neat as this theoretical spiral of “planning”, “acting and observing”, and “reflecting”. The stages overlap, initial plans quickly become obsolete, and the process is likely to be more fluid, open, and responsive.

“Planning” requires the practitioner to look forward, take into account the risks, and recognize real constraints in the situation. The plan needs to be flexible enough to adapt to unforeseen effects and previously unrecognized constraints, so it allows the practitioner to act more effectively, more wisely and more prudently over a greater range of circumstances.

“Acting” is deliberate and controlled; it is a careful and thoughtful variation of practice, and is critically
informed. It is guided but not controlled by plan and prior practice. In reality, it deals with real constraints and risks, fluid and dynamic. In addition, it requires instant decisions and practical judgment of the practitioner. The implementation of action plans will assume the character of a material, social and political struggle towards improvement.

“Observing” has the function of documenting the effects of acting. Its prospective is to provide the basis of reflection, not only for now but also in the immediate future. Careful observation is necessary because action will always be limited by constraints of reality, and all of these constraints will never be clear in advance. On the one hand, observation must be planned, so that there will be a documentary basis for subsequent reflection. On the other hand, it also must be responsive, flexible, and open-minded. The practitioner would observe the action process, the effects of action (intended and unintended), the circumstances of and constraints on action, the way circumstances and constraints limit or channel the planned action and its effects and other issues which arise. The whole process needs to be guided by intent to provide a sound basis for critical self-reflection.

“Reflecting” recalls “Acting” as it has been recorded in “Observing”, but it is also active. Reflection seeks to make sense of processes, problems, issues and constraints made manifest in strategic action. It takes account of the variety of perspectives possible in the social situation and comprehends the issues and circumstances in which they arise. Reflection can be both evaluative and descriptive: action researchers weigh their experience then judge whether effects (and issues which arose) were desirable
and suggest ways of proceeding; they also investigate then build a more vivid picture of life and work in the situation.

The criterion of success is not whether participants have followed the steps faithfully but rather whether they have a strong and authentic sense of development and evolution in their practices, their understandings of their practices, and the situations in which they practice.

3. Planning, Acting and Observing in the SpO2 Project

I participated in the design research of the SpO2 project as graduate assistant (design research), and worked closely with other members of our research team: principle investigators Dr. Heather Kaplan from Neonatology and Dr. Patrick Brady from Hospital Medicine; clinical research coordinator (CRC) Kristen Timmons from Hospital Medicine; co-investigators Eric Kirkendall from Hospital Medicine, Prof. Mike Zender from University of Cincinnati, Prof. Jen Mankoff from Carnegie Mellon University, and Katie Walsh from Anderson Center; data management specialist PhD Keith Marsolo from Biomedical Informatics; etc. At the same time, I was self-aware of my role in the process as well as my involvement in the project, and made notes as raw materials for further analysis and synthesis. “Acting” and “Observing” were going at the same time through the design phases, after my initial “Planning” occurred.
3.1 Planning PAR on SpO2 Project

First of all, it is necessary to clarify the “User” of my PAR study and the “User” of SpO2 project. For my own PAR study, I myself am the user - I am studying myself to improve designer’s participation of BMI projects, using SpO2 research project as a case. But for SpO2 display project, “Nurses” are users, and I am a designer to create solution for them. In other words, the “User” of my analysis of “Design + Medical” is not nurses, but me.

My plan of applying reflective study needs to coordinate with the timeline of the team’s plan. I planned to have preparations and attend meetings in the first month, then go for on-site interview, shadowing and observation of nurses in the following two months. As consolidation would be complete soon after on-site research activities with nurses, I would be able to create design solutions and finalize them based on feedback, which can be done in 1-2 months. Functioning prototype will be available after that.

In reality, the time before on-site research with nurses was prolonged from one month to two months, because I did not expect the vaccine process would be that long. Vaccination of pediatric diseases is required for all new employees at Children’s Hospital and it is strictly implemented. Consolidation of observation notes also took longer time than I planned, which will be discussed in detailed in the chapter about Reflecting on the SpO2 Project.
3.2 Acting in Design Research Process

The flow of “Acting” is presented in Figure 2.

Figure 2. Acting flow in SpO2 project
1. First of all, I obtained papers about biomedical informatics and SpO2 titration from our research team, my professor and online resources to read and prepare for the project. It is necessary to understand the context and some basic relevant medical knowledge so the conversation with medical staff will be easier in the future.

2. In the first kick-off meeting, I met the research team, which consists of doctors, informatics professionals, and medical researchers. I learned medical context of both nurses who take care of preterm babies at NICU (Neonatal Intensive Care Unit), and nurses who take care of children with bronchitis on hospital medical floor. The relation between Epic and monitors was also explained. Lead investigator also introduced the timeline of the research activities in the following several months.

After kick-off meeting, I had four meetings before on-site interview and observation with nurses- some are individual or small meetings, while some are big team meetings. In individual or small meetings with team members, we had deep discussion of what we’ve learned so far and clarified clinical context by fast hand-sketches. Big meetings are used to review progress in the past, plan next step and always keep everyone of the team on the same page.

3. Totally 16 on-site observations at both medical floor and NICU of Cincinnati Children’s Hospital were completed by our research team, among which I participated in four: two on the medical floor (A6S)
and two at NICU. Each observation lasted 1-2 hours and involved following a nurse through every step of his/her service while making notes. I observed not only the screens but also the people and the hospital environment, which always greatly impacts users. Other team members and I also interviewed nurses to get direct feedback about the questions that help our concern. Shadowing the nurses when they were working helped us understand more about their work and every-day life.

4. After each observation, the team would retell the story together and transcribe what we saw into notes. During the retelling, one of us would be the main story teller and he/she would speak out what he/she had seen and experienced during the on-site observation with nurses. Other members could add, comment or question anytime. One of us would be the note write and he/she needed to cut the continuous story into pieces, with clearly marked date, location and chronological series numbers (1, 2, 3...), so it will be convenient to categorize and analyze them in the following steps.

5. Notes and facts are organized after storytelling, but all the dots still lack connection. Therefore we need to consolidate them and create an inter-connected knowledge network, so the large perspective of user story can be clearly understood. When most of the observation notes were completed, we started the process of consolidation. We used Affinity Diagrams, Task Models and Flow Models to help us organize original knowledge and connect all the dots and understand both the large perspective and important details.
“Affinity Diagrams”: we broke the chronological order of note pieces and rematch all the facts, findings and opinions according to content. After revisions, finally we regrouped all the notes from 16 observations then came up with a complete affinity diagram, with big categories of “Responding to Alarms”, “Reviewing data in Epic” “Oxygen Titration and Desats”, “Shared Responsibility”, “Rounds Meetings”, “Handoff”, “Intersection of Alarms, O2 Management and Charting” and Epic charting. In order to make them more understandable and empathetic, we revised objective fact-statement into first person “I” statement.

“Task Models” illustrated specific activities that repeatedly occur in nurses’ shifts. For example, assessment, O2 titration, Epic charting, etc. These models were generated from our original notes.

“Flow Models” focus more on how the information is flowing and what’s the connection among all the roles that involved in this big network. It is worth noted that a “role” in flow model does not equal to a “person”. One person can act different roles, while one role can also be shared by different people. For example, a nurse can act as direct care provider, patient status monitor, data recorder and many other roles in one shift; the role “patient status monitor” is acted not only by nurse but also patient’s parents, machines that linked to patient and some other people or objects.

6. With the outcome of consolidation and our understanding of all the findings and models that we developed in previous phases, we were able to create a user journey map of nurses (Figure 3), so the
large perspective is presented in a visual way. User journey map is a commonly-used design tool which visualizes the path of a user from a starting point to the end, representing the different touch points that characterize the interaction. This visual representation is simplified by removing redundant details and keeping the core ideas. It is an important intermediate design product before our final design solution about SpO2 data display.

Data display concepts for key touch points in the user journey map were designed (Figure 4, Figure 5, Figure 6, Figure 7). In first concept (Figure 4, Figure 5), Current SpO2, FiO2% and O2 Flow data are showed in most recognizable places. Brief history overview information of past 4 hours is displayed next to current data, including max, min, average and target numbers. Distribution situation is visualized by gradient colors. Detailed history a detailed wave diagram that reflects changes through a period of time in the past, with the trend, changes, target range and out-of-range information highlighted. Supportive patient information is also available, e.g. what patient responses well. More text-description details will be available after clicking the “Read More” link at top-right corner of the screen.

The second concept alternative (Figure 6, Figure 7) simplifies the landing page by removing the detail history and relocating it to the next information level, accessible by clicking the “Detail History”.
User Journey Map

1. (Receive) Hand-off
2. Rounds
3. Provide Direct Care
4. Monitor Patient Status
5. Record Data
6. Understand Data
7. Respond to Alarms
8. Support Staff
9. Educate orientee & parents
10. Give Hand-off

About O2:
- Titrate O2
- Set alarm limits
- Review alarm limits
- Know alarm policy
- Support baby's breathing (vent)
- Comfort patient
- Suction patient and trash care

About NC:
- Understand big picture
- Remove monitors when patient improves
- Understand recent past in more detail
- Deliver therapy (PVC)
- Give respiratory treatments
- Assign work to other NCs
- Care for multiple patients
- Assess patients
- Tell patient to breathe
- Sign-out patients at night level
- Take vital
- Start feeds
- Give meds
- Check and fill IVs

interact w/ objects
(Epic, monitors, scratch-paper, & paper template)

interact w/ people
(orientee, parents, co-worker)

interact w/ patient
Figure 4. SpO2 data display concept 1 - when current SpO2 is out of range

Figure 5. SpO2 data display concept 1 - when current SpO2 is normal
Figure 6. SpO2 data display concept 2- landing page

Figure 7. SpO2 data display concept 1- detail page
It has not been tested and decided about which concept is better, but anyhow they have similar information modules about current data, overview data and detail information of SpO2, FiO2 and O2 Flow.

7. In order to collect direct feedback about the outcome of our consolidation and the design concepts of SpO2 data display, our research team organized six workshops with nurses at Cincinnati Children’s Hospital Medical Center- three with medical floor nurses and three with NICU nurses. Participating nurses of each workshop varied from 6 to 12. We were able to get longitudinal feedbacks about affinity diagrams and design concepts from our users.

### 3.3 Observing Myself

During the design process, I made notes about the events in which I was a participant. At the very beginning, I was not exactly sure how the notes should be structured so I initially broke down the structure into several points then tried it. After several activities, based on the amount of information and the effectiveness of the initial structure, I revised the bullet points and note structure (e.g. breaking “take-aways” more detailed into three branches; adding the “Confusions” column), so I had a better and more effective structure to continue making notes of myself in following activities. The revised elements of note include:

- **1. Time**
The process of self-observation is well planned and guided by the structure above. It not only clearly marked contextual information but also highlighted insightful core ideas - three kinds of take-aways, together with “design methods” and “confusions”, are the core and most valuable insights for the following “Reflecting” step, while other information such as time, location, participants and event are important contextual information. In addition, the structure is also responsive that additional notes can be fit into “others” category.

Among “take-aways”, I categorized notes into three groups according to their content: “designer’s feelings”, “research process” and “clinical knowledge”. “Designer’s feelings” mainly focuses subjective feeling and emotions as a designer within a medical research team, which makes the whole story of
how a designer participates in BMI project more vivid, real and interesting. “Research Process”
take-aways include thoughts, comments and experience about what I felt good or what I think need to
be improved in terms of designing activities. Analyzing these will give us a better view of how to work
efficiently and effectively in research and design activities. “Clinical knowledge” covers objective facts
and findings from material study, team meetings and on-site observations. Some of that can be as
general as a guide direction, while some can be very detailed that you won’t recognize without
shadowing the nurses.

4. Reflecting based on the SpO2 Project

With the self-observation notes on how I participated in the SpO2 project, I was able to look at them
both within an activity and across events and analyze them with reflective approaches. I collected
insightful data for each single activity, while there are also many interesting findings if we compare and
analyze the notes across different activities.

Most of the important findings can be concluded into the chart below (Figure 8):
Figure 8. Insights of each step grouped into three categories
The Following paragraphs illustrated these insights in detail, categorized into three groups: Designer’s Feelings, Research Process and Clinical Knowledge. Relations and connections between these insights and design solutions are also analyzed.

4.1 Designer’s Feelings

Designer’s feelings directly influence each step of research process. If we crop the first column of the big diagram above, and fit each of them into Russell’s Circumplex Model of Emotions (Russell, 1980) based on different level of “Pleasant” and “Activeness”, we will have Figure 9.

My emotion was active during the research process. It started “anxious”, then went into “excited” as the data collection more and more involved users. When we came to analytical phases, the tasks were challenging and not every effort was productive (which is common in research), so the emotion went down naturally. But when the consolidation was competed and we could go back to the users to collect feedbacks, I felt more pleasant and more active again.

1. I felt overwhelmed when I received the materials for the very first time. There are so many terms that I did not understand even after consulting a dictionary. It took me a while to really understand the relationship between different elements in this project.
2. I actively asked basic medical and clinical questions, especially when the project just started. There would be many terms and abbreviations that medical staff take for granted but unfamiliar to designers—well, most of the designers. We should not feel shy to ask about their meaning. Doctors will not know what designers know and what designers do not know, so asking medical questions also improves team internal understanding. Asking questions is also a way of showing attention and interest, which will be

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**Figure 9. Column 1 - designer's feelings**

<table>
<thead>
<tr>
<th>Designer's Feelings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Paper Reading &amp; Getting Ready:</strong></td>
</tr>
<tr>
<td>* 1. firstly feel a bit overwhelmed</td>
</tr>
<tr>
<td><strong>Research Team Meetings:</strong></td>
</tr>
<tr>
<td>* 2. actively ask questions about medical context</td>
</tr>
<tr>
<td><strong>On-site Observation:</strong></td>
</tr>
<tr>
<td>* 3. feel intimidated &amp; do not want to disturb</td>
</tr>
<tr>
<td>* 4. impressed by nurses' workload</td>
</tr>
<tr>
<td><strong>Retelling Stories &amp; Creating Notes</strong></td>
</tr>
<tr>
<td>* 5. uncertain about how detailed the notes should be</td>
</tr>
<tr>
<td><strong>Consolidation</strong></td>
</tr>
<tr>
<td>* 6. feel lost to consolidate observations that I was not present</td>
</tr>
<tr>
<td>* 7. cannot input any when discussion goes into clinical details</td>
</tr>
<tr>
<td>* 8. feel great when all dots are connected</td>
</tr>
<tr>
<td><strong>Workshop w/ Nurses</strong></td>
</tr>
<tr>
<td>* 9. feels nervous and excited to see so many nurses involved</td>
</tr>
</tbody>
</table>

Using Russell's Circumplex Model of Emotions

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valued by medical staff.

3. When shadowing nurses in hospital, I felt so intimidated and would try my best not to disturb their routine. Especially my first observation, I was not familiar with the environment and I had no clue what’s going on. I made notes and drew sketches of everything going on around me.

4. It is so impressive that how much work the nurses are doing during their shifts. They also have amazing ability to handle multiple tasks at the same time. Nurses work under a situation full of disturbance and changes. Decision making is going on almost every moment on their mind, either deliberately or subconsciously.

5. When retelling story and making notes, our research team often covered detailed clinical content, for example, name of medicine, specific Epic tab names, clinical operation procedure etc. As a designer, I am not sure about how detailed our notes should be. If it is too general, it will not provide much for next steps. If it is too detailed, it will increase the difficulty during synthesis. In addition, as a non-clinical member, it is even impossible to decide what is the most proper level of how detailed it should be. Therefore, thorough discussion with doctors and other researchers is in need.

6. Make sure to get involved in as many design activities as possible. If designer is absent for some, it might take even long time and more energy to catch up the progress. For example, based on the
experience and professional know-hows, I could hardly give out insightful comments when doing the consolidation about observations that I did not participated.

7. When coming to discussion about clinical details, I did not feel myself very useful, which is expected but still a bit frustrated. I care/understand more about the people, the behaviors and cultural things, but not able to deal with many clinical details or policies

8. The completion of consolidation is encouraging. When the consolidated models are completed, the relationship between different contents is clearly showed in a visual way and there are we feel so confident about what we’ve learned and how to continue the next steps.

9. Design workshop is exciting but also challenging. It is great that our research team was able to recruit a big amount of nurses to participate in our workshop and they make great job in providing comments and feedback. But it was not an easy situation to handle when the workshop was quiet.

4.2 Research Process Insights

There are insights about research process. Details are listed in Figure 10:
Research Process Insights

Paper Reading & Getting Ready:
* will be helpful to meet the research doctors earlier
* vaccination and procedures might be time-consuming

Research Team Meetings:
* fast hand sketches make discussion effective
* doctors in research team may have other tasks than research

On-site Observation:
* aware of physical env’t
* aware of interpersonal communication of nurses

Retelling Stories & Creating Notes
* too detailed notes are not easy for further synthesis
* can be time-consuming

Consolidation
* designers need to trigger inspiration of others
* so many methodologies to select
* important to differentiate “role” and “people”

Workshop w/ Nurses
* effective for nurses to grade/ comment on affinity diagrams
* not easy for nurses to come up comments just by reviewing concepts shortly
* 2-3 nurses in a group is better than more
* some nurses might not be that talkative

Figure 10. Column 2- Research Process
Some insights can influence the efficiency and effectiveness of data collection, for example:

1. It is important to contact and talk about the project with the team and research doctors early. It will be really time-consuming if designers do not get on the right track in time.

2. Designers should be prepared for complicated medical paperwork even before the project really kicks off. Tedious paperwork and procedures sometimes can have really negative impact on design schedule.

3. Hand sketches and primary prototypes make the discussions and meetings between doctors, researchers and designers much more efficient and effective. With something tactile and visible, non-designers will feel at ease to give out comments, opinions and correct the mistakes with ease. It is also important that when discussing the same piece of visual, people feel certain that the whole team is “on the same page” so there is less potential for misunderstanding. Besides making team discussion more efficient, hand sketches can inspire doctors and other team members then help designers collect better data about medical context.

4. Doctors in the research team have clinical responsibility during the research process, which means that it is impossible for them to devote 100% of their time into research. Schedules of meetings and design activities should be expected to be influenced by clinical emergencies.
5. During on-site observation, I not only studied the screens of Epic and monitors the nurses are using, but also paid attention to physical surroundings in hospital. Communication within medical environments is ubiquitous and accounts for a substantial part of healthcare practitioners’ daily routines, encompassing interactions in varying contexts and information sharing across temporal and spatial dimensions (Bossen, C. 2002). Environment context helps designers understand users empathetically. For example, hallways in hospital can be very busy, especially in the morning when medical teams are doing rounds, while in afternoon and evening it is much quieter. When nurses are working at computer stations in hallways, disturbance will occur more than in patient rooms. Speaking of patient rooms, some patient rooms can be very dark even during the day time and the only light there is the screens and devices...

6. Designers can also have lots of interesting finds if they are aware of interpersonal communication between medical staff. Care providers don’t work alone. A nurse works together with other nurses, respiratory therapist (RT), MDs and even patients’ parents. Interpersonal communication is also another important element of nurse’s shift.

7. Nurses feel comfortable to give comments to affinity diagrams with all the notes translated into the “I” statement. We used stickers of different colors indicating “agree”, “somehow agree” and “disagree”, and post-its for more comments.
8. It is not very easy for nurses to come up with comments about display design concepts by looking at designer’s concept in such a short time. It is better to collect feedback about design concepts with questionnaire and give them more time to think about it. In addition, it is more effective to give out design concepts one by one but not a whole lot at the same time.

9. According to the situation of workshops, we found that 2-3 nurses in a group during discussion worked the best. This size of group helps nurses be engaged into discussion and giving comments. When the discussion group has 4 or more people, nurses did not talk as much as what they did in smaller groups.

10. During the workshop with nurses, we find that not everyone is that talkative. Some nurses, especially the young or inexperienced ones, tend to be quiet and dare not to comment. Several pilot questions, or individual sessions, may be helpful to speed up the warm-up so nurses will feel more comfortable to make comments.

Some other insights influence the analysis process for context understanding, for example:

1. Occasionally the discussion will go deep about clinical details. When making notes of the story retelling session, notes can be full of clinical details that designers may feel lost, or at least need to
spend much more time to digest the meaning and then the connection of those.

2. Story retelling and consolidation after on-site observation can be time-consuming. Because of the amount of observations and the importance to be consistent with the real clinical facts, the flow is slow and cautious.

3. Designer should always be the one who trigger the inspiration of other members, especially when the whole team feels stuck. Even though designer’s clinical knowledge is limited, it is always helpful to actively try things out and bring it onto the desk. With some tactile materials, other team members, for example doctors and medical researchers, can feel at ease to make comment and consequentially have more and more thoughts on their mind. It is totally fine that the initial idea that designers proposed is wrong- only if the final result is good. For example, when our SpO2 research team is grouping note pieces, it is occasionally difficult to come up with category names at the very beginning. I would make up something for temporal use, until other names occurred to my team members. Therefore, we do not need to stare at a piece of blank paper and dare not step anywhere forward.

4. There are a variety of methodologies available to conduct consolidation. It could be confusing about which one fits the best. Designer’s suggestion about consolidation methods will speed up the design pace and give a clear direction of what should go next.
5. During the analysis, it is important to differentiate the term “role” from “person”. For example, a nurse can act as multiple roles during her shift, such as alarm responder, direct care provider, patient status monitor, etc, while one role can involve several different people and even objects - for example, medical devices, nurses and patients’ parents can all act as the role of “patient status monitor”.

4.3 Clinical Knowledge

Relevant medical papers about SpO2 include research from Augusto Sola, Laptook AR, Gandhi B, Ford SP and Cirelli, J.

From the synthesis diagram, we can easily find that analytical phases –“Story Retelling” and “Consolidation”- do not have any clinical knowledge collected, which indicates that these analytical phases only organize and clean-up but do not provide clinical knowledge to design research.

In addition, from the amount of useful clinical knowledge, it can be concluded that activities which directly involve nurses- “On-site Observation” and “Workshops with Nurses”- contribute the most to providing clinical knowledge. I.e., communicating with users is the most effective approach to collect relevant data.

Details are available in Figure 11.
### Clinical Knowledge

**Paper Reading & Getting Ready:**
- time-oriented data visualization is commonly used
- there is a desired range of SpO2(%) for infants on supplemental oxygen
- nurses have alarm fatigue

**Research Team Meetings:**
- way to titrate O2 is different b/w A&O & NICU
- two main screens for nurses: Epic & monitors

**On-site Observation:**
- multi-task & full of disturbance
- fast vs. slow decision making situation
- Epic has heavy interfaces
- input changes not recorded by machine, only manually
- infants w/ or w/o tracheostomy influences nurses attitude
- many personalized behaviours

**Retelling Stories & Creating Notes**

**Consolidation**

**Workshop w/ Nurses**
- alarm limits not always consistent with orders
- info about past average/max/min SpO2 is needed
- light bkgd concepts are more welcomed than dark ones
- “asleep” or “awake” makes a big difference

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Figure 11. Column 3- clinical knowledge
1. Temporal information is crucial in electronic medical records and biomedical information systems (Li Zhou, 2007).

2. Specifically for SpO2, it is important to keep SpO2% within a specific range over time, which has not been standardized but commonly agreed on 90%-95%. Many people assume that the blood oxygen saturation should be as high as possible, but that is not always the case. When babies are on supplemental oxygen (>21%), the potential of having hyperoxia increases dramatically if their SpO2 is higher than 95%. Hyperoxia is caused by healthcare providers. It does not occur in nature, and evolution has not equipped the body to deal with it (Augusto Sola et al, 2014). Therefore, we need to monitor babies’ SpO2 and give out alarms when the SpO2 is either too high or too low.

3. Fatigue to alarms has been studied in some papers (e.g. Augusto Sola et al, 2014). It is an issue among nurses, especially after a long time of working. It is important to keep this in mind when generating solutions for SpO2 project as the data display is directly linked to alarms. For most of the time, the alarm for SpO2 is only one among the many that can go off in hospitals.

4. Nurses have different approaches to titrate O2 on medical floor and NICU. Nurses who take care of children with bronchitis who stay on medical floor (A6S) adjust the O2 flow, while nurses who take care of preterm infant in NICU mostly adjust FiO2% (> 21%). These two kinds of approaches involve different data to display, collaborating with the SpO2 data.
5. For both scenarios (A6S and NICU), nurses mainly interact with two screens. One is the computer with Epic running, and another is the monitor with vital signs displayed. Epic and monitors are available in both in patient rooms and hallways.

6. Nurses play different roles during their work (Figure 12). The consolidated flow model below shows how the information flows between different roles, among which blue ones are the roles of nurses and the purple one is “patient”.

Figure 12. Consolidated flow model- except the purple “patient” role, all other roles are parts of nurses’ work
Nurse’s responsibilities include:

Teach

Support

Provide direct care

Develop medical plan

Respond to alarms

Monitor patient situation

Remember and understand data

Record data

Nurses’ work is also full of disturbance. It is common for nurses to simultaneously take care of several different kinds of tasks and remember the progress of each.

7. Decision making scenario changes based on nurse’s tasks. There two kinds of decision making system: system 1 and system 2 (Stanovich, 1999). When people are under system 1, decisions are made automatically in a short time. It is mostly intuitive, experience-oriented and there is no analysis going on. For system 2, which takes longer time, people will use analytical thinking and make decision according to the result of analysis. To the point of nurses both on medical floor and NICU, they are using system 1 to deal with situations which need their fast response. For example, when an alarm goes off, nurses usually have a quick glance of the screen then rush to the baby, without much time to read
details and data. But under situations like hand-off and rounds, nurses will usually have longer time to review the data and build up the large perspective of the patient with analytical thinking then come up with decisions which guide their work later. For two different kinds of decision making model, there are opportunities of each that we can display our data in the way the fits in nurses’ need.

8. Epic has heavy interfaces. Tabs, menus and forms look overwhelming on screen.

9. There is not a proper display of changes, and data about changes are all input manually, which is not an ideal solution. For example, the changes that happen to alarm limits, ventilator O2 flow or FiO2, medicine and so on are all recorded by nurses.

10. Patient’s status influences nurse’s attitude. For example, nurses treat babies with tracheostomy differently from the ones who do not have tracheostomy. Whether the patient is asleep or awake makes a big difference too.

11. Nurses have many personalized behavior during their work. For example, they have different ways of making notes on “scratch paper”, charting in Epic, suctioning, etc.

12. Alarm limits are not always consistent with ordered alarm limits, because there are usually multiple people who have the rights to change alarm limit. Therefore, a display to show the difference between
ordered and current alarm limits will be useful.

13. From the workshop, we learned that information about past average, max and min is needed. These data are all very straightforward and they help nurses understand a brief context effectively.

14. Light color background is preferred, but it might be false conclusion. We concluded this when showing nurses with paper prototype in a bright meeting room during the workshop. Nurses commented that dark-background prototypes look so dark and they might not like it as the patient rooms are usually dark. It is an interesting comments which shows the working environment makes difference to nurses’ preference to software systems, but it needs validation by really testing it in dark patient rooms.

4.4 How can these insights influence the design solutions?

Let’s crop the columns of Research Process and Clinical Knowledge, and then put them together. Connecting with the features of user journey map and SpO2 data display, we will have a diagram as in Figure 13.

From the diagram, we can know that insights from both Research Process and Clinical Knowledge consist of the content and the big direction of user journey map.
However, SpO2 data display design concepts only directly result from the clinical knowledge that I
studied from papers, group discussions, onsite observations and workshops. Insights of research process do not contribute that much to the design of SpO2 data display design. Analytical phases, such as story retelling and consolidation, are not directly helpful to SpO2 data display design either, as they do not collect new clinical knowledge.

Design features of the nurses’ user journey map include:

1. Flow is non-linear (Figure 14).

![Figure 14. Non-linear frame of user journey map](image)

According to the clinical knowledge that we learned during onsite observation, nurses are always multi-tasked, and their work is full of disturbance, so the visual which reflects their work needs to adopt a non-linear form to represent the flow of their work.
2. Surrounding people and objects are included (Figure 15).

We learned from onsite observation that nurses interact often with co-workers, patients, patients’ family, computers, monitors, etc. They are not isolated. It is useful not only to show what nurses do and think but also show the context of each activity. Therefore, there need to be many other characters that showed in nurses’ user journey map.

3. Text is wide-covered and precise.

The insights of retelling stories and consolidation indicate that wordy description is not easy to read and understand, and we also find during the consolidation that actually there are so many roles of nurses that we need to reflect in the user journey map. In order to cover all the important notes from our story retelling and consolidation phases, we need to make the text on user journey map precise, accurate and wide-covered.

Design features of SpO2 data display concepts are also analyzed in Figure 16:
Design features include: personalized clinical suggestions; clear hierarchy of “current data- overview-detail history” is showed; difference between “what it is now” and “what it should be” is displayed; including FiO2% and O2 Flow Rate as important supportive data to SpO2- ideally, changes applying to FiO2% and O2 Flow Rate diagrams on screen are linked to O2 devices.

1. New module of personalized clinical suggestions

This is inspired from that nurses have many personal preferences, so it is useful for nurses to put some
pre-set suggestions for themselves and also some other nurses, so there is a better understanding about this patient.

2. The hierarchy of “current data- overview- history in detail”

The display of this series of data is inspired from clinical knowledge about what information nurses need. Different decision making models guide designers to have different priority about current data, overview data and history detail data.

3. Difference between ordered limits and current limits.

From both onsite observation and workshops, we learned that ordered limits might be different from the current limits. Therefore, it will be useful to show both limits and the difference between them.

4. Interactive diagram of FiO2% and O2 Flow

Including an interactive diagram of FiO2 % and O2 Flow is based on the needs of recording changes and connecting O2 input and output data, which is an opportunity recognized during onsite observation. Adding both FiO2 and O2 Flow is also inclusive to cover the situations at both A6S and NICU, which is a fact that we learned starting from early meetings.
5. Conclusion

PAR effectively helped me participate in design research of SpO2 project and generate valuable insights.

Each insight provides useful information about different phase of the design process. Reflective process after participating was also successful.

The relations among insights and design solutions are visualized in Figure 17.
Analysis about the relation between insights, user journey map and data display concepts shows that data display mainly needs medical context and knowledge, and it is not closely related to other design insights. User journey map is not only relevant to medical knowledge but also connected to many non-medical findings that designer recognizes.

If we put user journey map, which is an “intermediate product” during our design process, together with data display, which is the “final product” of the whole activity, we will find that user journey map does not provide direct guide or support to the design solution of the final display- knowledge sources of the two do not overlap. So what is the value of user journey map In this case then?

User journey map is a comprehensive reflection of user’s story. We find that user journey map is not the direct information provider for data display design solution, but it shows where exactly the final solution of SpO2 data display is within nurse’s working system, and let people know that what we are working on is not solving the whole problem but opening an enter point to this big network.

In addition, by showing the relations among different elements, user journey map predicts the impact of our design concepts. By showing the relationship between one design concept and other element visually, the consequence of that design can be reasonably concluded. Positioning a design solution display into the journey map is like adjusting one point within an inter-connected net, so the changes of
other points can be reasonably concluded. For example, putting our SpO2 data display design concepts into our user journey map of nurses, we can know that it would make a big difference to activities of providing direct care about O2, monitoring patients and recording O2 data, while other sessions which are also important to improve patient care, such as interpersonal communication, is not much engaged.

Speaking of other designers in the future, it is helpful for us to show what we are solving and what we have not involved by designing a overall user journey map of nurses, so design folks can feel more comfortable to see the map and get ready to contribute to other opportunities of research and design which are exposed. Some day in the future, the complete system of nurse’s daily work will be improved as wholeness, but not separate parts, which will make a long-lasting beneficial impact.

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