Feeling the Life: A look into the Visual Culture of Life Scientists

Dhaval Vyas
Human Media Interaction
University of Twente
PO Box 217, 7500 AE Enschede
the Netherlands
d.m.vyas@utwente.nl

Hinal Bhatt & **Lorenzo Moroni**
Department of Tissue Regeneration
University of Twente
PO Box 217, 7500 AE Enschede
the Netherlands
hinalbhatt@gmail.com

Anton Nijholt
Human Media Interaction
University of Twente
PO Box 217, 7500 AE Enschede
the Netherlands
a.nijholt@utwente.nl

ABSTRACT

In order to deal with human biological problems, life scientists have started investigating artificial ways of generating tissues and growing cells – leading to the evolution of tissue engineering. In this paper we explore visualization practices of life scientists working within the domain of tissue engineering. We carried out a small scale ethnographic exploration with 8 scientists and explored that the real value of scientists' experiments (and simulations), reasoning and collaborative processes go beyond their end results. We observed that these scientists' three-dimensional reasoning, corporeal knowledge and intimacy with biological objects and tools play a vital role in overall success.

Keywords

HCI, Ethnography, tissue engineering, Visualization Practices, Regenerative Medicine

INTRODUCTION

According to the U.S. Department of Health and Human Services (HHS, 2011), annual US healthcare costs for 2011 are more than $2 trillion. Tissue loss and organ failure are considered to have played a major part in these costs with approximately 8 million surgical procedures being performed annually in the U.S. to treat these disorders. Regenerative Medicine is said to be an area of research that could bring better curing possibilities and decrease these expenses. According to the HHS, U.S. private sector has till date spent over $4 billion on the regenerative medicine research. And, new initiatives like FIRM (Federal Initiative for Regenerative Medicine) are expected to establish a global medicinal industry with expected potential of $100 billion to $500 billion worldwide by year 2020. With the potential of treating almost every tissue and organ of human body, regenerative medicine is expected to solve problems related to major diseases of our current time: diabetes, heart disease, strokes, cancer, HIV and so on.

Within the HCI and CSCW literature, we have seen extensive fieldwork on understanding practices of different knowledge workers: engineers (Suchman, 2000), architects (Schmidt and Wagner, 2002), designers (Büscher et al. 2001), clerical workers (Sellen and Harper, 2002) and even the professionals working in different fields of biology (O'Day et al. 2001; Vyas et al. 2007) amongst many others.

Scientists working in advanced biological fields, especially in regenerative medicine, come from a variety of background: tissue engineering, tissue science, biology, biochemistry, physics, chemistry, applied engineering, and many others. They facilitate each other's work by utilizing each other's expertise. In some cases their practices sometimes change or evolve overtime. As HCI practitioners we have to understand these new, emerged practices and be able to design new tools to support these practices. Especially, since biology is a visually-oriented field (see the next section), we need to provide implications for designing new visualization 'techniques' and 'technologies'.

Cell culturing (or tissue culturing) is a very fundamental step towards understanding the state-of-the-art research on regenerative medicine. Using an ethnographic approach, in this paper, we explore visualization practices of 8 life scientists working towards supporting and engineering for cell culturing processes. We explored their laboratory experiments and simulation sessions, their reasoning processes and their collaborative practices. Our aim here was to understand scientists' enactment of creating, using, and interacting with different biological materials and tools. It was observed through our field-study that because of the 'visual' nature of this field, life scientists bring value to their work by utilizing their three-dimensional reasoning and corporeal knowledge. We show that this is in fact a result of their embodied interaction and long-time engagement with different biological objects that they work with. We also conclude from our research that these life scientists build intimate relationships with the biological objects and other tools they use.

In the rest of the paper, we provide a short background on the visual aspects affecting biology professionals' work. Next, we explain our fieldwork settings, selection of participants and the results. In the end we discuss some implications for designing new technologies that can fit into this multidisciplinary field of regenerative medicine. Overall, we aim to bring awareness and attention of the HCI practitioners to this under-explored line of research.

BIOLOGY AND VISUAL ASPECTS

> *"…physiological function of the cell can be understood only in terms of the three-dimentional configuration of its elements……all biological phenomena, no matter what their complexity, can ultimately be accounted for in terms of conventional physical laws"*
>
> (Stent, 1968)

Evelyn Fox Keller (2002) describes that all life scientists, to a large extent, have the main goal of understanding and explaining the biological development in individual organism, i.e. 'making sense of life'. Life scientists use a wide range of models, metaphors, structures and tools to explain this process. The visual and multidimensional representations related to human biology (e.g. images, models) provide great insights into understanding the complexities of different organisms. Moreover, during most experiments life scientists have to observe spatio-temporal information related to reactions, growth or mutations within different entities of organisms (ranging from muscles to micro-molecules). This information can be observed in an efficient way through visual means. It has also been claimed that nearly all activities at cellular and molecular levels depend on form, colour and physical structures (Altman, 1998).

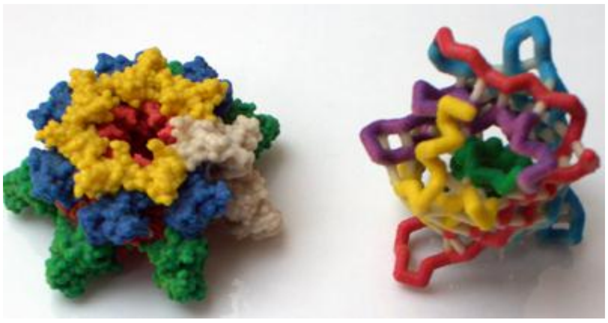


Figure 1: Physical replicas of anthrax toxin (left) and green fluorescent protein (right).

Historically, it has been shown that in order to better understand biology (especially molecular biology), life scientists need to think in a three-dimensional way. For example, Francoeur (2000; 2002) gave a detailed account on the role of materiality of molecular models and suggested that a three-dimensional representation of molecular structure can reveal several mechanical properties, support both qualitative and quantitative reasoning about the structure and allow us to articulate theories and concepts about them. To him, textual and statistical results about biological information reduce many important phenomena about the human biology, which can be better explained through a more physical approach. Figure 1 shows some examples of physical models (made of plaster or starch, using a rapid prototyping process) that are used to test theories and teaching purposes.

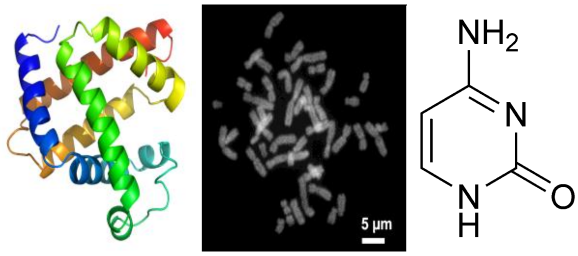


Figure 2: Three different visual representations used frequently by life scientists. A 3D protein structure (left), human chromosomes (center) and chemical structure of cytosine (right).

In addition, to deal with human biological problems, life scientists use different graphical structures related to cells, genes, DNAs and molecules. Many of their decisions are based on the embodied information (such as shape, size, colour and behaviour) of these structures that are used and explored during biological studies. See figure 2 for some frequently used visual information by biologists. Based on their specific field of research, life scientists use different computer-based or analogue tools to carry out visualization practices – sometimes even combining more than one device. They require dynamic and prolonged manipulation and articulations with these graphical structures.

THE FIELD-STUDY

Before we describe the field-study, it is important to explain a brief version of the process that is used by the life scientists working in tissue engineering research. Scientists normally start with a specific goal of research and a hypothesis related to cells or specific tissue that they want to test using different procedures and techniques. Specific cells are selected to be used in-vitro (outside organism's body) and external material is added to it maintaining specific environment by taking into account the timing, temperature, weight, and so on. In doing so biomaterials are used to focus on the specific parts of the cell that needs to be tested. A membrane is a physical object that allows only specific materials to pass through it. Biodegradable polymer is used as a carrier for inserting external materials inside the cell. Several versions of these cells are used with a variety of materials added into them to see what topology is best suited for research. Based on different cases different type of membrane and polymer techniques are used. For a cell to culture (grow or mutate) it could take from few hours to several days. Using different visualization techniques the cells are computationally processed and analysis is carried out at the end of it.

Our aim here was to understand life scientists' 'enactment' of building, using and reasoning for different biological materials during the cell culturing process. It is important to note that within the multidisciplinary research of tissue engineering one needs to understand working practices of not just the traditional biologists, who are involved in experiments but also the people who work closely with them – people who build biomaterials. These people also have biology-related backgrounds with expertise of engineering and model building. Our attempt was to investigate people who are one way or the other involved in the process of cell culture within the tissue engineering domain. Hence we selected the following 8 participants (Table 1) for our field study.

Participants		
#	**Work Environment**	**Research Projects**
1	Private Research Organization	Tissue Culture & Cytogenetic
2	Technical University	Tissue Regeneration: Cells
3	Technical University	Tissue Regeneration: Bones
4	Technical University	Biophysical Engineering: Cell Growth
5	Technical University	Biophysical Engineering: Modeling Techniques
6	Technical University	Biomaterials & Polymer Chemistry
7	Technical University	Membrane Technology for Human Cells
8	Technical University	Membrane Technology for Human Cells

Table 1: Information about the participants

We observed the laboratory sessions of these participants, interviewed them during their free time and also collected some information and experiences about their previous works and projects. In the laboratory sessions, we captured video recordings and at times we took notes. The focus here was to understand their visual culture that included different tools they use, processes and knowledge practices they applied during their research. Seeing scientists' practices in a holistic manner (starting from hypothesizing, experimenting, analysing and producing final results) was really important for us.

RESULTS

It was observed during the study that life scientists' visual culture was pervasive throughout their working practices. Three levels are identified from the results of our study, where the visual culture of life scientists affects their everyday practices.

1. Experiments and Modelling
2. Reasoning
3. Collaboration

In the following parts, we will show how scientists' visual culture affects their work practices at these three levels.

Experiments and Modelling

We were able to capture life scientists' live experiments as well as their modelling and simulation processes involving cell culturing. It was observed that overall 50-80% of their work was based in laboratories.

(a)

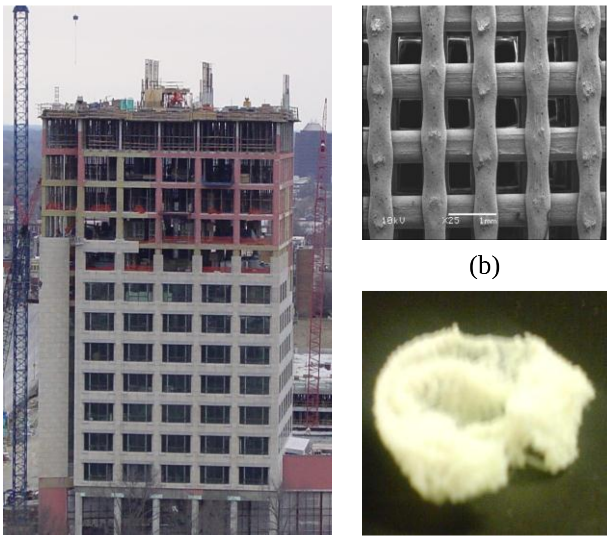
(b)

(c)

Figure 3: Laboratory session of a participant: (a) adding material in the experimental cell sample, (b) viewing and adjusting it in a microscope and (c) discussing how to proceed further.

For a routine cell culture experiment (figure 3), scientists worked in-vitro with the cells in a sterile cabinet as can be seen in figure 3a and depending on the hypothesis and the type of experiment they add several materials to the sample. Most often scientists make sure that they collect several samples to be able to quantify their final results and do statistical analysis. Depending on the type of experiment, the cell culturing process could take few hours to several days. Scientists working on simulations and modelling collaborate with the traditional biologists in order to fabricate, engineer and model specific materials that are needed for engineering tissues. In some cases, scientists use specialized devices to build 3-D models of membranes, polymer and cell structures. They need specific type of scaffold made with specific material, shape and weight that can be used during the experiments. With the use of advanced prototyping devices used in materials processing, biologists and scientists who design and develop biomaterials can in fact visualize the physical form of a specific shaped material and they both can help each other in forming a required shape of that material. Figure 4 illustrate an example of making a scaffold (skeleton model) of an ear of mouse, for the purpose of artificially generating a mouse ear. A scientist described the process of making such a scaffold as creating a building:

> *#: "The way a building needs support from rods and pillars, I also think about designing a skeleton of an artificial organ. I use micro plotter to create such a scaffold where cells will be seeded."*



(a) (b) (c)

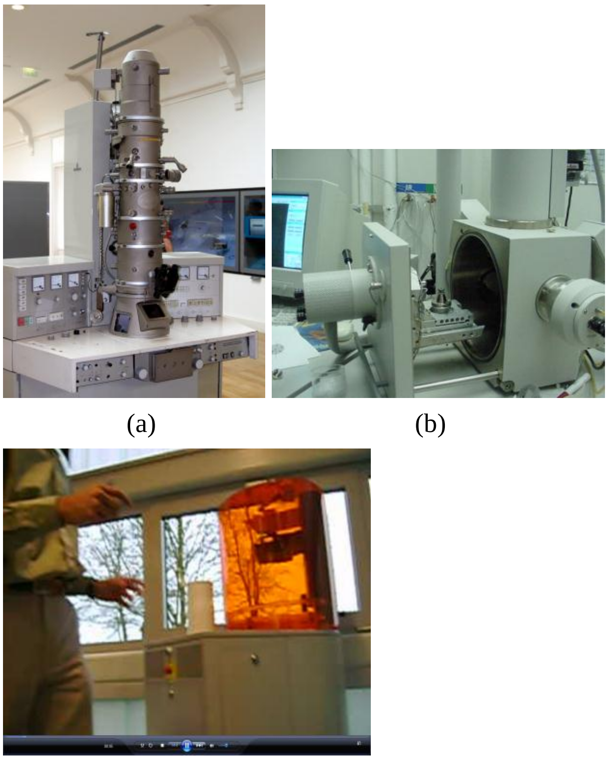
Figure 4: A metaphor of building (a) is used to model (b) and develop the scaffold for an ear (c).

In order to carry out experiments and modelling scientists have to use and deal with several heterogeneous media: physical as well as digital. Figure 5 shows only a few devices that were commonly used by these scientists. Often they needed to use more than one device and perform different activities on biological samples that they are working on. Especially, scientists who work on understanding the biological processes use several simplification techniques like FISH (Fluorescent In-Situ Hybridation), Raman scattering, and so on.

During experiment and modelling processes, visual information proved to be vital. Here are some quotes from two scientists.

> ***#:** "Right now the project that I am involved in makes use of lots of imaging. So for me it's a huge amount of data being acquired by imaging. The outcome of my work greatly depends on the imaging or the graphics that I acquire from a particular source."*

> ***#:** "Graphical structures that we use bear a lot of importance in our work. In our everyday work, we deal with various graphical structures. These cell culturing images… they can acquired by various modalities and techniques so there can be various ways in which we have to view these graphical images of cell culturing. We have fluorescent microscopic image, light microscopic image, electron microscopic image, atomic force microscopic images… All of these images bear different level of importance and bear different kind of information. These all depend on the aim of the research and method that we want to apply in our research."*



(a) (b) (c)

Figure 5: Images of different devices used in Modeling and Experiments. (a) Electron Microscope (b) Scanning-Electron Microscope (c) StereoLithography Machine.

Through out the field-study it was observed that these life scientists heavily used specialized microscopes, related imaging devices, and interactive computer graphics technology. These all required an 'active' and 'prolonged' handling and manipulation of the biological objects (experimetal cell samples) and onscreen models throughout different cell culturing processes.

> ***#:*** *"My work aims at forming bone cells from different materials in the in-vitro setting. The final thing would be to bring it to the clinic, but before that there needs to be lots of testing done. Throughout my research project, I will have to interact with different samples of bones again and again. I have to analyse and understand the growth of bone cells using several types of microscopes and bio-reactors. If the growth is less than expected then I have to restart the whole procedure using different compounds and materials. Thinking about this cells and try to understand the process of their growth is what I do most times while I am in the laboratory. Sometimes it makes me literally think as if I am inside of the cell."*

It was important to take into consideration various medium used, not only to understand how scientists worked with different visual information related to cell culturing processes, but also for understanding how these distinct media engaged scientists' bodies in different ways. Different machines, tools and materials afforded different modes of interaction and manipulation, and provided different kinds of insight into the cell culturing realm.

It was also observed that 'getting the feeling' about these cell functions was a habit amongst some expert workers. One of them said: "*the quantified data provides us the final evidence about my work but I need to feel this object too* (referring to a cell slide)". Scientists always try to think 'what is this structure saying.' The cell chip or cell samples embody use of several different artifacts used for creating it. To these scientists, the resulting sample or simulated models are not just another outcome of their research, the labour these scientists have put in gives them a sense of feeling about how it will behave in a given situation.

Reasoning

In the reasoning or the analysis part, we observed that scientists use a variety of processes and techniques to generate different visual representations to be able to analyse the behaviour of cells that they are experimenting with. In the following, we follow up the example of the artificial mouse ear discussed in figure 4. Figure 6 shows four different types of images, generated from four different staining techniques, the scientist used in order to verify whether the cells have cultured to the mouse ear scaffold in an appropriate manner. Figure 6a is a representation of cells using the Methylene Blue staining technique that indicates whether enough cells are attached to the scaffold so that further analysis can be carried out. Figure 6b shows growth of the cells and how they are interacting with each other. Figure 6c indicates the live and dead cells on the scaffold, using the florescent microscopy. Figure 6d shows an image using Phalloidin staining technique that can help the scientist to understand the detailed structure of cells.

These four procedures are typically applied in a linear fashion to be able to justify reasoning about a particular experiment. These different representations used to support deductive reasoning in the experiment. Such image-based thinking stimulates a demand for external representations and helps scientists to interpret and validate images and data by producing new visualization techniques (Gooding, 2010).

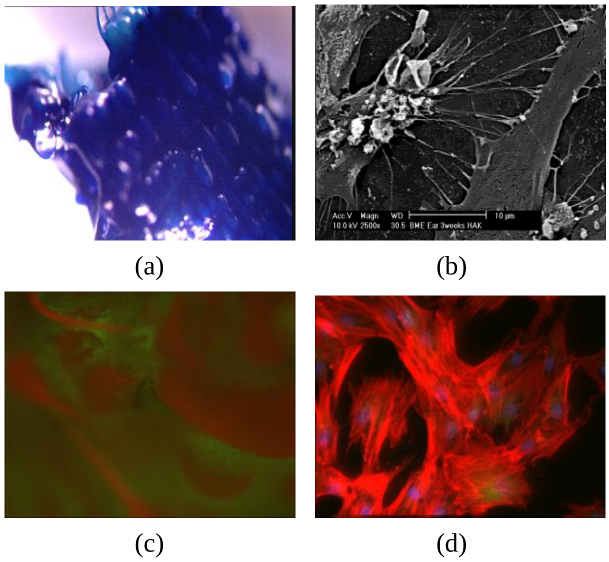


Figure 6: Four different staining techniques applied to the artificial ear cells.

Scientists also use computer-based tools to quantify the raw data of cells that they have built during cell culturing process. These tools allow them to generate graphs, statistics and eventually make conclusions about their overall work. However, the visual information was still considered the primary source as can be seen in the following comments by two scientists.

> ***#:*** *"For us, the structures, the size, and the shape of a cell are very important. Also the relative dimension that is the ratio of the length and the breadth and sometimes in cases where I am using the FISH technique then the amount of fluorescent that comes of out the cell is also important. There is also a post-processing involve from the graphics that we acquire in order to extract the information that we need."*

> ***#:*** *I normally view these images at two levels: At Raw level, which is an unprocessed version of the*

cell behaviour. And at Processed level that is computationally processed to generate detailed information about the cell behaviour. This final data depends upon the raw data. So, I work iteratively on raw and final data. If the raw data is perfect then it can be a final data otherwise I need to capture the process again."

Interestingly, the cell culturing process was seen not limited only to a means of producing representations of cells, it was also an activity to train novice scientists' 'bodily-reasoning' and 'imaginations'. To be able to *think intelligently* about these cell structures, they had to acquire skills to understand the function of a particular cell or the interactions between more than one cell types. Figure 7 shows a practice note from one of the scientists. It was created several years back but she still uses it as a guide. She comments:

***#:** "When I first joined this lab, I learnt all the 23 chromosomes by trying to remember their shape and formation and practiced by drawing them on my notes. I spent at least one day for each chromosomes."*

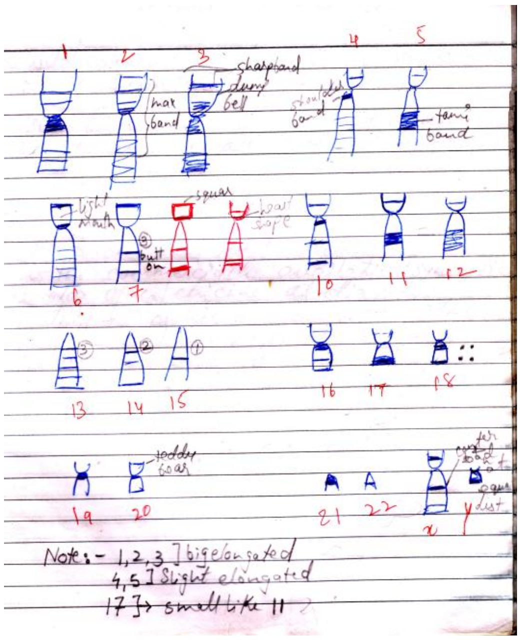


Figure 7: All 23 chromosomes. A practice note provided by one anonymous participant.

This example gives an indication that for these scientists to be able to think about cell structures they have to think in terms of shapes and bodily aspects of different biological objects. In figure 7 the participant had drawn two chromosomes in red colour as she found them really confusing. She indicates in the image the difference between a square shaped head and a curvy head for those two chromosomes.

As Merleau-Ponty (1962) argues that sensation and movement are intimately tied to visual understandings of form, it can be said that through the labour of constructing, manipulating, and navigating through different objects and models onscreen, scientists are literally able to come to grips with the form and function of cells, i.e. being able to efficiently make sense of cell. The biological objects and models that are produced over an extensive period of time should not be seen only as mark or traces of information. The whole cell culturing process in fact blur the boundry between what is physical and what is virtual.

Collaboration

Because of the multidisciplinary nature of regenerative medicine research, effective collaboration is an important part of its overall success. For supporting the cell culturing process, biologists need biomaterials like polymers to be able engineer tissues. As one of the biologists commented, "*we normally collaborate with a group that can fabricate specific materials that we want to try with cells*".

Visual nature of biology played its part here too. Scientists communicate with each others by using different froms of images, visual structures and other types of visuals.

***#:** "These images become a crucial communication tool. These graphical images help us explain to them what we exactly want. Because of these computationally generated graphical structures I can show my colleague by pointing to a specific portion of a cell."*

(a) (b)

Figure 8: (a) A chromosome metaphase rearranged using the FISH technique. In the circle a specific chromosome that is referred to as 9 o'clock. (b) A participant making a drawing to communicate her idea.

We also came across different languages scientists use and gestures they make to communicate with each other. During a session, a scientist working in cytogenetic frequently used terms like "*9 O'clock*", "*12 O'clock*" and so on to refer to a specific direction in a biological structure (See figure 8a). In this visual nature of biological research allow scientists to use their own bodies even in explaining. During the interview sessions, all the participants used gestures, showed illustrations, presentation slides and even drew (figure 8b) to explain certain phenomena that cannot be easily explained in normal language.

There were also some problems in collaboration. As we have shown in the previous section that the labour that scientists put into developing certain biological objects, structures and models, make scientists intimately close to these objects. One of the participants commented during an interview that at several occasions he had failed to explain certain things to his colleagues because they were not present in the laboratory when he was working on a project. In one case, he had to literally demonstrate the experiment again to the collaborators to make them understand this point. What we infer from this incident is that a scientist's work may not be 'fully' understood by the other people, because of his constant and iterative engagement with the biological objects and models and the embodied and three-dimensional knowledge he has used to develop these objects. This was not about the limitation of a verbal language but the complex overall phenomenon that was difficult to explain.

DISCUSSION & IMPLICATIONS

This work should not be seen as a full fledge, complete account on visual culture of life scientists. In fact, it should be seen as a way of making sense of the advanced biological research. One of the main claims of this paper is that the value of life scientists' working practices includes three-dimensional reasoning, corporeal knowledge and intimacy with biological objects and tools.

We were especially interested in understanding the 'enactment' of these scientists in their working environments. What was observed through out our exploration was that the visual information and different visualization practices of these life scientists played a larger role. Overall, these graphical and visual information supported by microscopic and computer generated images help scientists in the following aspects:

- They provide evidence and results of their research. As some participants expressed, these images are the outcomes of their research.
- Moreover, these 2D (or 3D) visuals help better understand what is happening at the micro and molecular level.
- They help in communicating and presenting the results in a desired way so that other people could make sense of it.
- They are also a collaboration tool for the colleagues and collaborators to understand what a scientist desire from them. This eventually improves the working process.

It must be noted that these visualizing and modeling practices of cell culturing challenge the narrow conceptions of understanding structures as a rational activity. The physical and mental labour that is put into the whole research activity is recusrsive and iterative. Throughout different activities, scieintists use craftwork, creativity and use their own embodied knowledge to enhance their scientific reasonings. Such cell structures and models, to a certain extent, are interactive objects since they demand participation and continual transformation from the scientists.

The above mentioned insight in the visual culture of life scientists provides us with a different perspective towards visualization and knowledge practices. Life scientists' longitutional engagement with the biological objects allow them to gain and develop three-dimentional thnking and corporeal reasoning. This allows them to think about their own work in a way that may not be possible by the others – establishing a specific identity in the biological objects that they are working with. Based on our exploration we also derive several implications for designing new technologies to support life scientists' work. After observing life scisntists' visulalization and knowledge practices, we believe that scientists' intimate understandings, creative thinking and physicality (or embodiment) related to biological objects and tools they use should be given more attention.

Support Intimate Understandings: As we explored from our research that through continuous and iterative interactions with different biological objects, scientists could understand these objects in a way that no one else can. For designing new technologies, we need to take this into account and build systems that can allow scientists to establish intimate understandings with the objects that they are working with. By making the scientists physically involved with the system (and not just mentally) could lead to an engaging experience of building different biological objects.

Support Creativity: It was clear that in a multidisciplinary research of regenerative medicine, experts from different backgrounds have to work together in a creative fashion to come up with new ideas and explain some unexplored biological phenomenon. These scientists work with a huge amount of data and they have to keep track of it. In fact, this is one of the major problems life scientists face these days. Designers can think of new ways of visualizing and representing information, providing supports in a way that scientists can keep track of their different on-going processes, allowing annotations on different visualizations that can be used next time when they work together in team.

Sustain the Physicality: As we saw during this research that the physical dimension involved in the manipulation and handling of different biological materials was the key for understanding and producing new cell and cell structures. This infact offered a means for researchers to use their bodies to incorporate structural knowledge. In addition to this, life scientists also carry their knowledge of cell forms, forces and movements throughout their own bodies. Designers should ensure that their new tools allows scientists to use their bodily knowledge.

CONCLUSION

It is observed during this field-study that life scientists' physical understandings play a vital role for making important decisions. This is certainly not a new conclusion. In fact, historically, scientists have been using different physical models and replicas to enhance their three-dimensional understanding of different biological phenomenon. However, from a design point of view it is important to understand how life scientists deal with their biological objects and what new technologies could be designed to support and enhance their current working practice.

The main reason to bring the visual culture of life scientists to the HCI community is because this field of research has not been well studied from a human-factors point of view. Especially, when research programs on regenerative medicine could bring cutting-edge solutions to life threatening problems (HIV, cancer, etc.) in a less expensive way, we believe that more human factors research will only improve the current understandings of biological.

ACKNOWLEDGEMENTS

I would like to thank all the participants of this study for their valuable time and detailed insights. Thanks also to my supervisor Dirk Heylen and Hemant Unadkat from providing valuable comments on an earlier version of this paper.

REFERENCES

Altman, R.B.: Bioinformatics in Support of Molecular Medicine. Proceedings of AMIA Annual Symposium, Orlando, FL, 1998.

Büscher, M., Mogensen, P., & Shapiro D.: Spaces of Practice. In W. Prinz et al. (Ed.), Proceedings of the Seventh European Conference on Computer Supported Cooperative Work. Kluwer Academic Publishers, (2001), 139-158.

Gooding, D. C.: Visualizing Scientific Inference. Topics in Cognitive Science, 2010, 2: 15–35.

HHS. U.S. Department of Health and Human Services. http://www.hhs.gov/news/press/2011pres/05/20110513c.html (last accessed on 30th June 2011)

Keller, E. F.: Making Sense of Life: Explaining Biological Development with Models, Metaphors, and Machines. Cambridge, Mass.: Harvard University Press, 2002.

Francoeur, E.: Beyond Dematerialization and Inscription: Does the Materiality of Molecular Models Really Matter? International Journal for Philosophy of Chemistry 6/1: 2000, 63-84.

Francoeur, E.: 'Cyrus Levinthal, the Kluge and the Origins of Interactive Molecular Graphics', Endeavour 26/4: 2002, 127-31.

Merleau-Ponty, M. Phenomenology of Perception. New York: Humanities Press, 1962.

O' Day, V., Adler, A., Kuchinsky, A., and Bouch, A.: When worlds collide: molecular biology as interdisciplinary collaboration. Proceedings of the Seventh Conference on European Conference on Computer Supported Cooperative Work. Kluwer Academic Publishers, (2001), 399-418.

Schmidt, K., and Wagner, I.: Coordinative artefacts in architectural practice, in M. Blay-Fornarino et al. (eds.): Proceedings of the Fifth International Conference on the Design of Cooperative Systems, IOS Press, Amsterdam, (2002), 257-274.

Sellen, A. and Harper, R.: The Myth of the Paperless Offices. MIT Press, MA, 2002.

Suchman, L.: Embodied practices of engineering work. Special issue of Mind, Culture and Activity, 7(1/2), 2000, 4-18.

Stent, G.: That Was the Molecular Biology That Was. Science 160/3826, 1968, 390-91.

Vyas, D., de Groot, S. and van der Veer, G.C.: Searching and Archiving: Exploring Online Search Behaviors of Researchers. In Proc. of HCI International (2007). LNCS, Springer- Verlag. 360-364.