13. Designing life in the (in) visible world: Stem-cells as epistemic objects and bio-objects in the interpretive flexibility perspective

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Introduction

The stem cell field is explicitly multivalent. It combines ethical, political, legal, social and cultural forces together with the biological processes. In 2008, two Special Issue published in Science as Culture brought the STS debate on stem cells to the international stage (Geesink et al. 2008). Those specials discuss the history of stem cells underlying the ambivalence of expectations and illusions. It is a long story, still ongoing, full of successes and failures, but also of promises kept and others that will never be maintained or are still waiting to be fulfilled.

Stem cells are materially visible due to the development of molecular imaging, which also makes them modifiable and combinable into new life architectures. To observe the "naturalness" of cells, it is necessary to make them visible, thanks in part to the power of microscopy technology, which has fostered the concept of making the invisible visible in many fields (Maestrutti 2008). Microscopes (from optical to confocal microscopy) makes cells observable and visible in the laboratory and also in the public debate space (Nowotny and Testa 2011). The cells are extracted, removed, separated from their environment and they become artificial to be seen by placing them on a plate, and only then do they move back into "natural" territory. The «invisible natural» is seen as a powerful design action, as Knorr-Cetina (1999) said, biological science draws the "artificial" design action that makes cells "natural" elements.

Particularly, in mammals there are two types of stem cells: embryonic, isolated from the inner cell mass of blastocysts; and adult, found in the various tissues of fully developed mammals. In a developing embryo, stem cells are responsible for differentiating into all specialised cells; adult stem cells are responsible for maintaining the normal turnover of regenerative organs, such as blood and skin or intestinal organs. The differentiation between embryonic and adult is enriched with further attributes that make stem cells an object of knowledge still being explored. There are many diseases and conditions in which stem cell treatment is being investigated: diabetes, arthritis, Parkinson's disease, Alzheimer's disease, osteoarthritis, stroke repair, spinal cord injury repair, heart attacks, anti-cancer treatment, vision repair, skin repair.

The basis of biological science is founded on knowledge of cellular life, which becomes one of the objects of study in the biomedical field in relation to the possibility of biotechnological manipulation and observation of stem cells (Franklin 2006). Current research is moving in this direction to find out how cell reprogramming takes place in order to closely investigate the differences with stem cells and find possible clinical applications. This is a field in constant evolution, extremely competitive and ethically sensitive in the social and scientific debate. Internationally accepted terminology distinguishes stem cells as totipotent, pluripotent and multipotent (Eriksson and Webster 2008).

In the last 20 years, and particularly in the last decade, significant knowledge developments have driven basic, translational and clinical advances in the field of stem cells and regenerative medicine. The most relevant experimental advances have occurred in the generation and differentiation of pluripotent stem cells and in the field of stem cell maintenance in different types of culture to three-dimensional (3D) cell technologies (Liu et al. 2020). An introductory distinction can be made between adult stem cells, which are characterised by a multipotency level as they can produce functional derivatives of the original tissue and precursors, and embryonic stem cells, which are totipotent as they can differentiate into all cell lineages. Particularly, embryonic stem cells are derived from the internal cell mass of blastocysts that make up an embryo at the 5-6-day stage of development. The cell mass at this stage of development contains pluripotent cells, meaning that they could differentiate into any cell lineage and any tissue.

To visualise stem cells, it is necessary to develop a molecular insight in order to intervene at the biological level, raising ethical, legal and political issues. Biological science bases its assumptions on the life of cells, becoming, even in the common imagination, a vital world with its own rules, behaviours and roles. In the scientific debate, they emerge as an autonomous entity with a life of its own, becoming a subject of controversy even in the public and political debate. The chapter sees stem cells as heterogeneous objects that undertake different natures and forms in relation to the contexts they pass through, where the question of *visibility* remains constant (Nowotny and Testa 2011; Cattaneo et al. 2013) because science needs to know them.

Observing the relationships that make cells visible and materially manipulable the chapter proposes to adopt the perspective of Science and Technology Studies to examine the different modes and meanings that stem cells acquire in crossing different techno-scientific worlds. The concept of interpretive flexibility is used to investigate how stem cells could be interpreted by different conceptions and by different social and scientific groups. The concept of interpretive flexibility, initially theorised by Social Construction of Technologies (SCOT) scholars (Pinch and Bijker 1984; Bijker 1995), allows us to capture the process of the ongoing construction of scientific process until its closure in a stable form of knowledge. Scientific research processes related to the differentiation, production, cultivation, use of stem cells in and out the labs fit well to becoming an empirical case study of use of interpretive flexibility concept as they continue to be the subject of lively scientific in the lab and in many spheres of the social world. The concept of interpretive flexibility was originally illustrated by Pinch and Bijker (1984) – pioneering exponents of the SCOT – in their classic study on the bicycle, which noted that the stabilisation of the object as we know it today was the result of extensive and complex co-construction processes between different relevant social groups, such as designers, users, markets, etc. The SCOT was criticised for closing the user problem too early and not showing how users could actively modify stable technologies (Mackay and Gillespie 1992). Later studies have expanded the concept of interpretive flexibility to pay more attention to the internal diversity of social groups themselves, the exclusion of certain groups, as well as political restrictions and constraints (MacKenzie and Wajcman 1999; Williams et al. 2005).

With this in mind, the chapter proposes to apply this articulated concept to the observation and study of stem cells, a complex scientific object that becomes visible in the making: extracted, cultivated, and materially manipulated in the laboratory, they become codified knowledge not only in scientific discourses but also in ethical and public ones. They have been travelling for some 40 years towards greater forms of stabilisation, through adaptations and negotiations sustained and connected to expert knowledge networks inside and outside the laboratory. They are scientific objects that from fluid and malleable seek forms of stabilisation in different clinical fields. The aid and guidance of the concept of interpretative flexibility can make it possible to observe how stem cells – in the complex journey that leads from scientific practice in laboratories to the transition into clinical practice – take on various forms and are gradually adapted into diversified and more stable knowledge.

Extracted from tissue and blood (human and animal) and manipulated in the lab, stem cells act visibly (Nowotny and Testa 2011) in laboratory practice in various forms. They are daily partners to be cared for, they are relevant partners in the processes of cultivation, differentiation, and cell reproduction, they become actors to scientific practice in articles, become intermediaries in gene therapy treatments in different areas of clinical practice, and encounter controversy in the public space. They are complex biological

objects that from lab to clinical practice seek and find forms of interpretative stabilisation.

In the perspective of approaching stem cells as complex partners of scientific practice, this article proposes below to observe them as epistemic objects (Knorr-Cetina 1999) and as bio-objects (Vermeulen et al. 2012).

The chapter is divided as follows: a focus on the story and the representation of stem cells in the public and scientific debate; some methodological notes; a section on the theoretically oriented analysis of the findings.

Short history of stem cells and public debate

The history of stem cells begins in the mid-19th century with the German biologist Ernst Haeckel who first used the term stem cells ("stamzell" in German) in scientific literature. Other scientists began to use the term to refer to single parent cells of a cell lineage. This hypothesis remained unproven until 1963, when Ernest McCulloch and James Till showed the presence of progenitor cells capable of renewal in mouse bone marrow. Specifically, they cultivated the mouse blastocyst (i.e., the set of cells obtained after fertilisation) obtaining pluripotent embryonic stem cells. A few years later, in 1981, with the improvement of laboratory techniques, Martin Evans (Nobel Prize winner in 2007) succeeded in isolating and growing the first stem cells from mouse embryos until thousands were obtained. In 1998 at the University of Wisconsin-Madison, scientist James Thomson and his collaborators derived the first embryonic stem cell line using embryos donated for fertility treatments that had gone unused. For the first time, embryonic stem cells are isolated and cultured from human blastocysts, creating stable cell lines over time. The publication fuels the ethical debate on what blastocysts are: a murder for those who consider the blastocyst a person, an ethically legitimate act for those who see in supernumerary blastocysts, derived from assisted fertilisation or abortions, small cell structures useful to understand biology and genetics and for regenerative medicine. The situation is different for adult stem cells (blood, tissue, cord blood, etc.), which from a legislative point of view are not used for the purpose of fertility treatments. Adult stem cells already have many therapeutic uses for leukaemia, retina and skin and some cancer therapies (Eriksson et al. 2008).

The history of stem cell research found a turning point in 2006 with the discovery of IPSCs (Induced Pluripotent Stem Cells), which earned scientist Yamanaka a Nobel Prize for medicine in 2012. These are induced reprogrammed stem cells that enrich the picture of promise and therapeutic possibilities. Cells that can be grown indefinitely in vitro and, depending on artificially modifiable culture conditions, can generate different types of differentiated cells. It is a type of stem cell generated by the addition of four genes and it is able to induce a cellular differentiation. iPSs are so called because they can induce the differentiation of most cell types in an organ (such as pancreatic and neural cells). iPS

cells and embryonic stem cells share the ability – cultured under precise conditions in the laboratory – to divide and produce all kinds of specialised cells with the hope that they can be used to replace cells or tissues in patients who have incurable diseases or damaged genes (Takahashi and Yamanaka 2006). What makes iPS a promising research object is the ethical aspect because the generation of iPS does not use embryos in the early stages. However, there are still obstacles to the production of iPS, as they behave differently from stem cells, possibly due to incomplete reprogramming of the cells and/or genetic changes acquired by iPS cells during their growth.

The use of these new cellular objects is being pushed in the conservative and Catholic public debate as it mitigates the issue of using embryos. In 2014, this is how Yamanaka himself presented them after winning the Nobel Prize:

> The induced pluripotent stem cell (iPSC) technology is instrumental in advancing the fields of disease modeling and cell transplantation. We herein discuss the various issues regarding disease modeling and cell transplantation presented in previous reports, and also describe new iPSC-based medicine including iPSC clinical trials. […]. The use of iPSCs in disease modeling, cell transplantation, and clinical trials could therefore lead to significant changes in the future of medicine. (Inoue et al. 2014)

Yamanaka himself in 2020, however, does not hide the problems still present in research on IPSCs, which makes them perhaps less promising than hoped for:

> Human pluripotent stem cells such as embryonic stem cells (ESCs) and induced pluripotent stem cells (IPSCS) provide unprecedented opportunities for cell therapies against intractable diseases and injuries. Both ESCs and iPSCs are already being used in clinical trials. However, we continue to encounter practical issues that limit their use, including their inherent properties of tumorigenicity, immunogenicity and heterogeneity. (Yamanaka 2020)

The two strands, human embryonic stem cells and induced pluripotent stem cells, find applications but retain risks and do not resolve controversies. The potential of stem research, whether embryonic, IPS or adult, is as enormous as the accompanying ethical debates. Embryonic stem cells became a central object of policy choices for research funding in all developed countries, starting with the USA, the country where they were first isolated. In the USA, the possibility of using them in government laboratories fluctuates, a pattern that is also repeated in the more general international scene in Europe and other continents. In 1995, Bill Clinton made federal funds legal for research on stem cells obtained from embryos. The decision came at the end of a heated debate on the ethics of cloning human embryos for therapeutic purposes, a decision firmly rejected by many religious groups and the pro-life movement. Instead, many scientists believed that this research could bring new treatments for diseases. Scientists were only allowed to study stem cells taken from frozen embryos that remained unused after in-vitro fertilisation. George Bush vetoed embryonic stem cell research in the early 2000s and then in 2009 President

Barack Obama again removed the limits on that funding. Donald Trump decides to zero out federal funding for medical experimentation involving the use of tissue from aborted foetuses. Recently, Biden's Democratic administration overturned Trump's decision by lifting the ban on government researchers conducting research with embryonic stem cells, emphasising the importance of fetal tissue research for the creation of models of the human immune system, essential for vaccine development, as was the case for Covid-19, and promising for imagining treatments against cancer and AIDS.

The world scene reflects this same ambivalence of positions. In Italy, the sector is regulated by Law 40 of 19 February 2004 on "Regulations on medically assisted procreation". This law recognises the embryo as a subject of rights from the moment of fertilisation, avoiding the use of embryos for any research. In 2005, Italians voted in a referendum to repeal this law, but the quorum was not reached. Few laboratories used human embryonic stem cells, others used them unofficially. However, over the years, the law has been amended several times concerning the production and cryopreservation of embryos (Perrotta 2013).

Research questions and methodological notes

This chapter uses the concept of interpretive flexibility to observe how processes of stem cell interpretation move towards greater stabilisation inside and outside of laboratories. Stem cells have a twofold trend: on the one hand they remain open and controversial objects of knowledge, a typical state of epistemic objects in the networks of different social groups, on the other hand they try to follow the process of greater interpretive closure towards bio-objectification (Webster et al. 2011) when they become more stable research objects and more ready for therapeutic uses. The process of bio-objectification brings stem cells into the realm of commercialisation (Waldby and Mitchell 2006; Rajan 2006) and exploitation for reproductive and clinical work (Waldby and Cooper 2008) and produces new classifications and different biological artefacts.

The analysis proposed in the article develops a reflection started within a broader ethnography carried out between 2008 and 2013. Various methods and techniques were used: field notes, interviews with researchers, focus groups, autonomy of researchers. The data were collected in a cellular biotechnology lab at the University of Milan. The laboratory comprises 25 researchers (senior and junior) with expertise in molecular biology, biotechnology, pharmacology, bio-informatics, and works on international projects in an extensive network of collaborations with laboratories of excellence in Europe, the USA and other parts of the world. During the observational work, twenty-five semi-structured interviews were conducted with the aim of narrating and observing scientists at work among microscopes, chemical hoods, computers, notebooks, and among cells. The interviews and observational work made it possible to look at how stem cells are discussed in the lab, how

the cells are treated, monitored and how they are moved towards therapeutic trajectories. In the laboratory under investigation, the working section dedicated to stem cells, also in relation to restrictions due to Italian legislation, involves few people and no public research funds can be used for this type of research. The use of human embryonic stem cells is aimed at the derivation of neurons that become diseased in Huntington's disease.

Cells in the laboratory must be made visible – through complex technical procedures of extraction, purification, cultivation differentiation – in order to become objects with which to dialogue and to keep healthy. In some cases, they are allies, in other cases, they are problematic companions, but nevertheless part of the sociomaterial life of the laboratory. The under investigation laboratory studies pluripotent stem cells with the aim of finding uses in molecular and pharmacological screening and identifying strategies for therapeutic intervention in the molecular alterations evoked by the diseased gene of Huntington's Korea. They do research with embryonic stem cells from abortion or supernumerary cells (which derive from blastocysts from in-vitro fertilisation not implanted in the uterus) purchased abroad (in Italy legislation prohibits their production). The aim is to develop research strategies capable of transforming pluripotent cells with general capacities into neural cells with particular abilities in order to study diagnostic and/or therapeutic potential.

Stem cells as epistemic object

The concept of epistemic object from the perspective of Karin Knorr-Cetina (2007) focuses on the social, ordinary and everyday mechanisms of knowledge construction, located in the micro-practices of laboratories or other delimited habitats of knowledge production practice. Scientific knowledge in the various disciplinary fields is thus inscribed both within narrow networks and also within wider networks that constitute epistemic cultures that produce beliefs, ways of doing things and negotiated practices. Knorr-Cetina defines the concept of epistemic cultures as a diversity of scientific activities, depending on the different scientific fields, not only in methods and tools, but also in types of reasoning, ways of establishing evidence and relations between theory and empirics. The concept of epistemic culture helps us to grasp those practical processes that are internalised in the way knowledge is created and practised.

Studying epistemic cultures means renouncing the unity of a single cultural paradigm of knowledge since the various fields of scientific knowledge are the outcome of cultural and practical processes that construct research objects, models and meanings over time. The practice of these knowledge objects is an open process resulting from the resistance and adaptation of human and non-human elements intertwined in research. Around the processes of signification and sedimentation of knowledge concerning a specific object, such as the case of stem cells, categorisations and significations are produced that remain

open and the agency of that object of knowledge is constructed by moving from one construct to another. The lab becomes an extended and wide-ranging space where natural and social elements move from the molecular biology bench, to writing practice, to relationships with the clinic, institutions and patients. We therefore apply the concept of epistemic object to stem cells, research objects present in a wide range of practices, from basic to applied research. The most frequently used processes concern their characterisation for specific uses in a certain field (brain, tumours, blood, etc.) and the processes of differentiation, which enable the production of different cell types, such as neural cells, skin or blood. Stem cells are also involved in basic activities but require high expertise in handling biological material. In the laboratory, pluripotent stem cells are subjected to biotechnology-mediated processes that can transform them from one state to another with the aim of producing new cell cultures, in this case neural, for future gene therapies.

Standardised procedures and experiments are put into practice to make cells epistemologically knowable. In this sense, stem cells are epistemic objects (Knorr-Cetina 1999) in relation to the role and the mobile ontology they play in the scientific practices in which they are generated and involved. They take on different natures and forms according to the context in which they are shaped. In this regard, it is reported two quotations from an interview with one of the junior researchers from the investigated laboratory who talks about the discovery of cells in his/her experience. In the following excerpt, the process of making the object visible and manageable through the experimental practice of scientific knowledge can be clearly seen:

> Pluripotent cells, embryonic stem cells, are an extremely useful tool for understanding how tissues are formed. Many wonderful papers have been published in the field of the nervous system, showing how we can obtain cortex, striatum, black matter or dopaminergic neurons from embryonic stem cells, according to the instructions we give them. This means that embryonic stem cells are plastic, capable of responding to the work that is done with them, and that neurons of a hitherto unknown cell quality can be obtained. So, it's not so much the fact that we produce neurons from stem cells in the laboratory, because over the years several articles have said that neurons are made from stem cells... no, let's say that you produce those particular neurons, perhaps those that are affected in the disease that is being studied, from stem cells. I don't know if this means that there will be a cure soon or not but based on the fact that well-guided embryonic stem cells can give us those specific neurons, we're really galloping towards the idea that this could soon become therapeutic. Programming neurons is part of the alchemy of scientists, what we do in vitro is to change the fate of the cells, yes fate is the key word in talking about stem cells. (Valentina, biologist, young researcher)

The epistemic object is defined by the variations, shifts, drifts, rotations it encounters. These objects of knowledge have power, produce effects, construct their own environment with humans, and shape the course of research. The object, despite its determination and specificity, necessarily maintains levels of openness that anticipate future and potential developments.

In the following quote, we see how the same object is produced and re-articulated in different ways. In the history of stem cells, the arrival of IPS in the experimental field turns the research field to imagine new scenarios of potential uses and future stability:

> And then there are IPS (a special type of stem cells), with these stem cells you can do other things in vitro. In this case, you start from the somatic cell and you bring it back to the stage of the stem cell, you can make a model of the pathology on the slide… it is a way to consolidate the power of the knowledge that you are building with the cells. The beauty of these cells (IPS) is that in modelling them you bring the genome of the person in vitro into the lab, and you can pressure them and turn it into a neuron following protocols. Protocols are being consolidated in order to stabilise the procedures to be done to achieve a certain result with a certain degree of quality. The ingredients are not bad at all: today we have good means of culture. Of course, you also have to imagine what you have to do to be able to see them, to understand whether these cells that you imagine you have seen on your slide really exist. With stem cells (or IPS), you can intervene in the process of cellular development in all directions, which means that you can change the direction that you make your cells take… (Marco, biologist, young researcher)

Researchers explore the different meanings stem cells take on in practice. The cells reveal different information structures and incorporate different and plural meanings. For the construction of meanings, the researcher describes the different networks of practice in which the cells are immersed. This is a nexus of interconnected practices, formed by materially mediated interdependencies between the different communities of practice in the workshops.

Narrative from the field shows the flexibility of research practices that find space in the creativity of the laboratory. In this space stem cells must be constructed as visible object and to do that they are constantly in flow, never fully formed (Knorr-Cetina 1999). It is their ability to be unstable and in motion that define cells in their epistemological representations of objects not quite understandable yet. The stabilisation of knowledge around the object of study "stem cell" is the effect of categorisation process that takes shape within actions that involves subjects and objects, pieces of cultural and material worlds such as biomedical and biotechnological research questions, grants, moral and ethical issues, microscopes, measuring devices etc.

Stem cell as bio-object

The bio-object concept (Vermeulen et al. 2012) is useful for discussing techno-scientific practices that translate the process of scientific knowledge into a visible object, as in the case of stem cells in recent decades. The term bio-object refers to all those biological artefacts, such as pluripotent cells, products of synthetic biology or genetically modified organisms, that create new forms of life with important effects on biomedical research

and commercial and ethical developments. What is recognised in the literature as the process of bio-objectification occurs, that is process through which life becomes an object of research, producing at the same time new forms of life that redefine the boundaries between what is natural and what can be defined as biologically manipulable (Webster et al. 2011).

If the previous paragraph attempts to discuss stem cells as objects of knowledge under construction and, therefore, manipulable for researchers, this paragraph reflects on the biotechnological process that makes biological elements materially observable as bio-objects. The *bio* suffix captures the ability of objects to make visible biological matter, bringing about modifications, transformations and alterations. Biotechnologies shape, construct and visualise bio-objects, which are configured as material-epistemic containers that transcend boundaries and contexts, between laboratory and clinic, between patient associations and political arenas, and thus the tensions involved in stabilising standards and protocols that produce new knowledge and cultural practices (Bloomfield et al. 2010).

For the purposes of our discussion, the bio-object becomes a conceptual tool to look at the biotechnological processes that make visible the stem cell after being dealt with by scientists in the form of research questions and hypotheses, experiments, research findings, etc. The process of bio-objectification makes clear how historically available technologies co-constitute biomedical definitions of what is considered pathological and/or normal. This interdependence constitutes a fertile research ground for STS scholars, who also look at how medical science creates definitions and classifies knowledge according to standards and categories, in turn establishing scientific and normative protocols (Vermeulen et al. 2012). Stem cells understood as bio-objects configure knowledge assemblages that seek greater stability, the focus of practice shifts towards medical knowledge production and biomedical technologies. As bio-objects, stem cells become more visible, but also standardised pieces of knowledge.

Here there are three examples of this increased visibility, stable autonomy and standardisation of stem cells. In the first case the scientists engaged in the research were asked to represent the object "stem cell" of their research practices with an image or a metaphor. Researchers can see stem cells under the microscope able to fix them in snapshots. The words of the scientists reveal how the process that makes stem cells knowable and visualisable in bio-objects is constructed using biotechnologies capable of opening up definitions and leading to new closures. Thus, for example Luciano sees cells as objects with their own autonomy and beauty:

> Cells are beautiful tools when they are plump and vital, when they are healthy, when they grow regularly and can be reproduced, when they smile. Are beautiful when you observe them and they are perfectly concentric and not too confluent, when their outline is well-defined and they appear translucent, are beautiful tools when they are healthy and allow me to discover a new physiopathological mechanism, so that I can think of new therapeutic strategies. They are beautiful tools when the lines that arrive from the international biobank are easy to reproduce

> and we can find nice cells to cultivate. Cells are beautiful tools when we can think of experiments aimed at transplanting cells in view of future therapies. Cells are beautiful when we can use cells from tissues (as in IPS) and thus bring the patient's genome into the lab and conduct experiments targeting therapies, collaboration with other labs, companies, clinics, and so on. (Luciano, biotechnologist, senior researcher)

In the second case, stem cells intersect technoscientific worlds using different visualisation technologies. The researchers learn to figure out, handle and recognise stem cells through visualisation technologies. The various technoscientific processes of translation (characterisation, cultivation and differentiation) in the use of stem cells in the laboratory are combined with those of scientific communication (publications and public debates). In order to strengthen their visibility and reputation, cells must be translated into more stable knowledge in the form of data and images:

> On the one hand, we try to see the stem cells through microscopic technologies, we have to be familiar with their vision, learn and see them well, then, on the other hand, we choose the most meaningful and relevant images of the cells for publications, in relation to the objective of the paper and the journal to which it is to be submitted. (Lucia, biotechnologist, senior researcher)

In the third case the representations offered by researchers show cells as living objects with which to remain in relationship in everyday laboratory life. But stem cells, on the other hand, are also materialised and proposed by researchers as objects that begin to live almost independently because of their potential for new applications in therapeutic fields or even in the biobank market.

> It takes years to bring stem cells close to their therapeutic use. We are collaborating with other laboratories and other hospitals to strengthen the practice of using Ips. We work with groups studying Parkinson's, a disease better known than Huntington's. We believe we can transfer expertise from one disease to another. We are learning to take tissue from consenting patients to operate cellular reprogramming to neural cells. There is still much to be done but gene therapy is the goal of our work. We work for therapies, to have the possibility in the future to help patients live better with their disease. Producing healthy neural stem cells for use on Huntington's patients where the neural cells are damaged, that is our goal. (Chiara, biotechnologist, senior researcher)

Examining stem cells as bio-objects is a way to observe the visible and multiple forms performed inside and outside the labs. The laboratory is the place where stem cells become manipulable in research practices and flexible in their meanings. The flexibility of possible interpretations is revealed in the research hypotheses, procedures, and standards adopted, which in turn allow for closure in bio-objects capable of crossing different scientific, political, economic and social arenas. This is a temporary closure that brings with it a standardised form of knowledge capable of traversing different social worlds.

Stem cells are not "given things" that can be investigated as separate objects from the interactions that produce them, since they, as objects of knowledge, only emerge through expert and technological interactions. Stem cells – embryonic, adult and induced pluripotent stem cells – keep dominating the scene as new and promising material objects of knowledge.

In conclusion, we propose that stem cells are a mobile, multiple and fluid research object. From an STS perspective, it is an object that preserves a wide interpretative flexibility (Pinch and Bijker 1984; Bijker 1995). Stem cells are epistemic objects because they are relational and contextual tracts of knowledge produced in the lab. The initial interpretative flexibility, played out mainly in lab practice, gradually encounters forms of interpretive closure that can be appreciated more theoretically with the bio-object concept. This contributes to viewing stem cells as a public object that takes autonomous form in scientific communication and then in public space.

The concepts of epistemic object and bio-object captures the process of their temporary stabilisation. Particularly, the concept of epistemic objects looks at stem cells as a scientific issue in the sphere of laboratory practices (Knorr-Cetina 1999). Laboratory practices understand them as objects of knowledge in the making, seeking stabilisation between scientific practice, and the construction of research designs, questions and hypotheses. If the concept of epistemic object underline the process of knowledge construction, the concept of bio-object observes how stem cells become visible and more stable, showing standardised biomedical properties and characteristics (Vermeulen et al. 2012).

The theoretical concepts used outline a technoscientific assemblage in which stem cells become effects of epistemic cultures (Knorr-Cetina 2007). Epistemic cultures are characterised by inter-relationships between knowledge and already hybrid forms of knowledge. In this knowledgeable relationality, cells become epistemic objects that enact meanings in hybrid and flexible forms capable of crossing different social worlds. A first form of visualisation is thus found in classifications that enclose the epistemic object – thus, the stem cell – in a knowledge form such as the scientific articles and graphic representations that make biological elements otherwise invisible to the human eye. To do this, stem cells go through the process of bio-objectification. The concept of bio-objectification (Vermeulen et al. 2012) is a conceptual tool that allows us to observe how biology can only become objectively knowable through classifications that enact interpretative closures. This is the case with the description proposed by Luciano that shows how stem cells are "beautiful" if they arrive healthy after having passed through, for instance, both scientific and legal protocols and standards governing international biobanks. But they are also "beautiful", for example, because they promise future therapies for diseases that still lack a cure. The process of bio-objectification thus has the effect of constructing a sociomaterial object that emerges outside research practices to enclose itself in scientific representations that require social and legal legitimisation (Nowotny and Testa 2011; Cattaneo et al. 2013).

The different degrees of interpretative flexibility that accompany stem cells in their design processes are defined in laboratory practices that manipulate stem cells as epistemic objects (Knorr-Cetina 1999). Laboratory practices understand them as objects of knowledge in the making, seeking stabilisation between scientific practice, and the construction of research designs, questions and hypotheses. We are dealing with how scientists assemble the material processes that make visible the artificial design tensions, growing into standards and classifications, which we can understand with the concept of bio-object (Bloomfield and Doolin 2011). The concept of bio-object observes stem cells as objects able to find out the biology that could lead to new discoveries. We have seen this in the words of scientists, showing how stem cells can become visible through snapchats encompassing human and non-human actors intersecting heterogeneous networks. Whereas in the first concept the cells are still something vulnerable, not-stable, and still under construction with regard to their definitions and conceptualisations, in the bio-object concept the stem cells become visible as autonomous configurations.

While with the concept of epistemic object we observe the social life of stem cells in the laboratory, with the bio-object we observe how the stem cell becomes a more stable object in the social and public perception inscribing possible imaginaries of future cures and therapies. Moreover, stem cells, showing a high degree of interpretative flexibility, are able to ensure cooperation between different social worlds from lab to public space.

The STS theoretical-conceptual framework allows to observe the interrelations between public, ethical and political issues. Following stem cells has made visible how the practice of science is intertwined with the public discourses. Furthermore, the different uses of stem cells will bring out more exciting developments in the fields of personalised medicine and the treatment of incurable diseases.

There are many challenges that remain open even within the scientific and therapeutic field, and in the public space, underlining the tension between the totipotency of human embryonic stem cells and the potency of other bone marrow, blood, skin and iPS stem cells. Stem cells remain still open scientific objects travelling in search of their future definitions and stabilisations.

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