Point Loma Nazarene University

Identification of Alternative Conceptions held by High School Students Regarding Stem Cells and Stem Cell Research

A thesis submitted in partial satisfaction of the

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by

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The thesis of Julie Rene (Miles) Gallagher is approved, and it is acceptable in quality and form for publication:

Chair

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I dedicate this thesis to my loving and wonderful family

To my husband, Patrick Gallagher, who has always stood steadfastly and lovingly beside me through all the laughter and tears the last 25 years.

To my parents, Paul and Pamela Miles, who have always loved and believed in me even when I sometimes lacked in that belief myself.

To my grandparents, Frank and Mary Miles & William and Marjorie Ludlam, who provided the foundation, love, and encouragement for all my future achievements.

To my children Kelly, Rory, and Megan who sacrificed, motivated and supported me with their love and understanding, and were my best cheerleaders…understand that with love, hard work, prayer, and indomitable spirit anything is possible and you can do and be anything you so desire!

To my “new” daughter Karly and in memory of her mom, who through their own struggles showed me that giving up is never an option…understand that we are family and you can depend on us to love and protect you.

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Abstract

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By

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Master of Science in General Biology

Point Loma Nazarene University, 2011

Dr. April Maskiewicz, Chair

The purpose of this study was to determine the existence of high school students' alternative conceptions regarding stem cells, and explore the underlying themes and contexts of these conceptions. Following a qualitative exploratory approach consisting of one-on-one semi-structured interviews of 37 high school students, a concept-based (thematic) classification table was created from the emergent themes identifying related alternative conceptions. Student interviews revealed that students held naïve conceptions in almost every stem cell topic area. Some naïve theories were held by individuals, others were held by several students. With the emergence and identification of alternative and naïve conceptions regarding stem cells, instructors can be informed of the problems students may face in understanding stem cell biology and this information can be used to help students make connections between what they already know about cells and the new stem cell topics that instructors desire to teach.

Stem cell research is a popular topic in our society today, especially following the signing of an executive order by United States President Barack Obama requiring the removal of “Barriers to Responsible Scientific Research Involving Human Stem Cells” on March 8, 2009 (Federal Register, 2009). This order lifted restrictions on federal funding of human embryonic stem cell research; both angering the abortion opponents and exciting those who believe that stem cell research could produce treatments for many diseases. On December 2, 2009, thirteen new human embryonic stem cell lines were approved for federally funded research under the new stem cell policies requiring the donation of embryos under an ethically sound informed consent process. This news brought a renewed interest and great debate about the pros and cons of stem cells and stem cell research (National Institute of Health (NIH), 2009). In the State of California Senate bill 471 (Romero & Steinberg, 2009) was signed in 2009 by Governor Schwarzenegger to create “The California Stem Cell and Biotechnology Education and Workforce Act”. Subsequently, the California Institute for Regenerative Medicine (CIRM) was created to develop and provide educational resources on stem cells and stem cell research for high school students in an effort to educate and advance stem cell research in the state (CIRM, 2011). Most recently, in the first few months of 2011, the FDA approved the use of embryonic stem cells in three clinical trials with others to soon follow, all with the substantial potential to find cures and treatments for spinal cord injuries, diabetes, cancer, stroke, heart disease and more (Wagner, 2011). However, at the same time, opponents in Minnesota were attempting to rush through the legislature a bill called the “Human Cloning Prohibition Act” (A2612-2011), which would criminalize stem cell research, prevent the creation of jobs in the regenerative-medicine-based industries, and restrict access to potential life-saving therapies (Wagner, 2011). According to Wagner (2011), a professor of pediatrics and director of Minnesota University Stem Cell Institute, "the public needs to understand the fact that it isn't even possible to clone a human being, as well as, the risks and benefits of embryonic stem cell research. Additionally, Wagner (2011) states that there are three main reasons to continue with embryonic stem cell research: "1) Cells from blastocysts continue to teach us how to make adult stem cells into more effective therapies, 2) Current methods of adult stem cell reprogramming require the introduction of genes that are far too risky for use in people, 3) New embryonic stem cell treatments are now in clinical trials". The pace at which stem cell research is evolving is a hectic and the public needs to be kept informed and up-to-date on the changes so that we can make educated choices regarding stem cell research.

As a high school educator, it is important to recognize and address students' alternative conceptions regarding stem cells so that we can help them move towards more scientific conceptions. Educators are unable to effectively address alternative conceptions in the classroom unless they are aware that the alternative conceptions exist; either in themselves and/or in their students. Identifying students' ideas and recognizing the alternative conceptions that may differ from scientific conceptions, before trying to promote conceptual change in students, can be difficult for educators. Research has demonstrated that high school students often hold alternative conceptions for explaining various biological phenomena because their ideas make sense to them for the situations they have been confronted with, and these ideas have some kind of predictive power. Students sometimes develop naïve conceptions or theories prior to having any formal training in a subject. Some of what they figure out is correct; others are not. When these theories are nonscientific they are referred to as “naïve” (or sometimes “intuitive”) conceptions” (Grotzer, 1996). These naïve conceptions are just as hard to identify and change as alternative conceptions, which are learned in more formal settings, such as classrooms. When students encounter new information that contradicts their alternative conceptions it may be difficult for them to accept the correct scientific conception because it seems wrong to them. Since their expectations don’t fit with the “new” scientific conception the new information may be disbelieved, thought of as irrelevant, or ignored all together (Horton, 2007). Some students may partially accept the new conceptions, making only minor changes to their previously held alternative conception(s). Occasionally, students may be able to fully accept the “new” scientifically correct conception and completely revise their alternative conception. However, because the “new” scientifically correct idea is often presented in a learning environment where memorizing the information is tied to some type of reward, such as grades, it is quickly forgotten following the test because it does not make as much sense to them as their alternative conception. This contributes to the difficulty educators’ face in recognizing that the alternative conceptions may still exist.

There is little to no research (qualitative or quantitative) available in professional literature regarding alternative conceptions that high school students have regarding stem cells and stem cell research. The primary focus in the literature appears to be that which addresses ethics and ethical boundaries based on people’s opinions regarding stem cells and stem cell research (Wainwright, Williams, Michael, Farsides, & Cribb, 2006). High school students’ alternative conceptions about stem cells and stem cell research should be of interest to science educators (Driver, 1989) because the study of cells, as the basic unit of life, provides numerous opportunities for understanding stem cells (e.g., mechanisms, reproductive strategies, ability to undergo differentiation into various cell types, and embryonic development).

The purpose of this study was to determine high school students' alternative conceptions regarding stem cells, while also exploring the underlying themes and contexts of these conceptions. The phrase "stem cells" is used in this paper to represent both the biology of stem cells themselves as well as the biology related to stem cell research, but not the ethical issues surrounding the use of stem cells. More specifically, the main objective for this study was to determine the existence of various themes of alternative conceptions that are held by high school students regarding stem cells, and subsequently to develop a classification (taxonomic) scheme of these alternative conceptions. Curriculum can foster a variety of conceptions (i.e., naïve and/or alternative conceptions) that can be problematic and/or impossible to erase. Having knowledge of naïve/alternative conceptions can enable the instructor to consider how to initially teach about stem cells, since that awareness provides instructors with insight into their student's thinking, and subsequently gives the instructor direction as to what they need to address in the curriculum. It is also essential for designing effective assessments, along with "distracters" to evaluate students understanding of stem cells using these instruments. Furthermore, compiling a classification of student's alternative conceptions may help to serve as a stimulus for discussions among instructors as to what concepts and models are most important for students to master, as well as, how to present those concepts and models most effectively.

Literature Review

Theoretical Perspective

Grotzer (1996), states that “we need to both reveal and address [students’] naïve theories and help [the students] to see how the scientific theories lead to more powerful explanations than their naïve constructions”. Constructivists agree and additionally have completely rejected the idea that a person can simply pass on information and expect that the learner will have an understanding of that information (Smith, diSessa & Roshelle, 1993). Constructivists emphasize that prior knowledge plays a huge role in learning and in order for the student’s prior knowledge to be transformed and refined into more sophisticated forms; the students need to construct new meaning/new knowledge for themselves by confronting their naïve and alternative conceptions (Smith et al., 1993). Piaget (1963) stated that learning must be actively and internally constructed by the learner rather than explained completely by another person”. Julyan and Duckworth (2005) also concluded that “knowing words used to explain a phenomenon does not necessarily reflect an understanding of what the words describe”.

Students’ Conceptions

There are numerous studies that address student’s biology conceptions including scientific, alternative and/or naïve conceptions. Some of these studies have shown that alternative conceptions in biology exist no matter the age or background of that person (Hewson & Hewson, 2003), and that these alternative conceptions are scientifically inaccurate assumptions and explanations constructed by a person through his/her experiences. Studies of alternative conceptions usually entail extensive qualitative analysis of responses to questions or analysis of responses to various instruments about the topic in order to uncover the subjects' point of view that results in the meaning they make and their understanding. No students enter high school biology classes as blank slates eager to gain scientific understanding of biology. From early in life, students are making sense of their world and "evolving a robust and serviceable set of theories about mind, matter, life, and self.

Relatively few papers have been published that cover student conceptions regarding stem cells. Plagge (2008), sought to determine whether the amount of stem cell biology knowledge a person has influences his likelihood to support embryonic stem cell research. She found that students lacked scientific knowledge regarding stem cells and utilized incorrect terms/concepts, yet maintained specific ideas and opinions about their support either for or against using stem cells for research. She concluded that the "biology of stem cells needs to be taught in school for a more scientifically literate society" and that it is "imperative that the public have at least a fundamental understanding about the biology of stem cells—it is the public who will be asked to vote on issues of regulations and funding, sit on juries where lawsuits will be tried, or perhaps even find themselves in an elected office where stem cell policy will be debated" (p. 36). There is a good possibility that students leaving high school without a basic knowledge of stem cells will never be exposed to the science behind stem cell research and will solely base their opinions and choices regarding stem cells on what they hear in the media, their spiritual advisors and others lacking scientific understanding.

Stem Cell Biology

Embryonic and adult stem cells are the two types of cells that show what is called "stemness". These two specific cell types are special types of cells that give rise to, or differentiate into about 200 different kinds of cells in the human body (Scott, 2006). This includes, muscle cells (Caplan, 1991), bone cells (Caplan, 1991), neural cells (Crews, Miller, Ma, Nixon, Zawada & Zakhari, 2003; Scott, 2006; Vergara, Arsenijevic & Del Rio-Tsonis, 2005), and blood cells (Rajasekhar & Vemuri, 2005). Stem cells are cells that have the ability to divide, grow and create a variety of new cells that are specific to certain body tissues. There are several different types, or potencies, of stem cells. "Potency" is a term used to describe how many types of cells a stem cell can become. Stem cells can be classified as totipotent, pluripotent or multipotent.

Totipotent cells are cells that are very similar to pluripotent cells in that they both have the ability to give rise to all cell types in the body. However, totipotent cells are probably the most important and versatile cells in the body because they can produce an entire fetus or new organism. Totipotent cells are cells created within the first couple divisions of the zygote (fertilized egg) and these cells will continue to divide to make many copies of the totipotent cells in the next couple of days. At approximately day four post-fertilization, the totipotent cells begin specializing and become pluripotent cells and lose their ability to create a fetus or new organism (Crews, et al., 2003; Rossant, 2007).

Pluripotent cells are cells that have the ability to become one of the three germ layers; endoderm, mesoderm or ectoderm. These germ layers then differentiate into their appropriate tissues of the body. For example, some pluripotent cells will differentiate into the ectoderm and give rise to the skin and nervous tissues. According to Crew, et al., (2003) pluripotent cells are found in all cells in the body, and have the ability to differentiate into any embryonic or adult stem cell tissue, except for the placenta. This means that pluripotent cells are unable to give rise to a fetus or adult animal (Crews, et al., 2003; Rossant, 2007).

Multipotent cells are stem cells that can only form a limited number of cell types. For example, within the nervous system tissue (which may in itself be pluripotent) there is a group of stem cells called neural stem cells that are capable of forming all of the specific nervous system cells (i.e., neurons, glia, and oligodendrocytes) (Crews, et al., 2003) but cannot form skin cells or muscle cells. These specific neural multipotent cells are important to development, as well as, to the regenerative and healing properties within the nervous system (Crews, et al., 2003; Rossant, 2007).

When used in research, embryonic stem cells are removed from the inner cellular mass (ICM) of an embryo at about four days post-fertilization. The four-day old embryo is referred to as a blastocyst and is made up of about 150-200 cells that are of two different types: the ICM and an outer layer of cells, which will eventually become a part of the placenta (Jung, 2009). When the ICM is removed from the blastocyst, it maintains pluripotency with the ability to give rise to all other cell types (Caplan, 1991; Scott, 2006), though it cannot give rise to the entire animal (Rossant, 2007). The blastocyst itself is destroyed in the process (Caplan, 1991).

The first embryonic stem cells to be isolated were extracted from mouse blastocysts by British researchers in 1971 (Kim, Oh, Park, Ahn, Sung, Kang, Lee, Suh, Kim, Kim & Moon, 2005). It took another 27 years before American scientists were able to isolate and culture the first human stem cells (Kim, et al., 2005). In 2006, much controversy surrounded President George W. Bush's usage of his veto power to block the Stem Cell Research Enhancement Act (Bush, 2006). Bush's arguments as to why stem cell research should immediately be curtailed helped to perpetuate some of the naïve/alternative conceptions that the public accepted as being the absolute truth regarding stem cell research. Bush (2006) told the public in a press release that there were only two choices in stem cell research: either the embryo is destroyed for stem cell research or the embryo is adopted and grows into a baby. However, what Bush neglected to mention was that embryos left over from *in vitro* fertilization (IVF) "have no practical chance of developing into persons; their fate has been sealed before the researchers have anything to do with them" (Harman, 2007, p. 209). There are a number of reasons (to be addressed later) why more embryos are harvested than can be implanted, but the fact is that these surplus embryos (in the thousands) are discarded annually and are not permitted to grow into a baby (Manninen, 2007; Camporesi, 2007) as suggested by Bush.

Human embryonic stem cells (hES) are usually garnered from excess embryos from either couples seeking *in vitro* fertilization (IVF) or from embryos left over from a pre-implantation genetic diagnosis (PGD) (Wainright, et al., 2006). IVF embryos have clinical potential to be used in treatments and are generally frozen and viewed as "surplus to requirement" (Wainwright, et al., 2006). The reasons that more embryos are created for IVF procedures than will be used in implantation include: 1) women produce a large number of eggs in a single cycle, all of which are extracted for IVF; 2) Not all embryos are implanted due to the risk of multiple pregnancies, which can be dangerous to the woman and the fetus(es); 3) the high costs of IVF (more cost effective to harvest more than one or two embryos at a time since it costs anywhere between $10,000 to $30,000 for one treatment cycle (Gurevich, 2010); 4) better to fertilize all the eggs derived in the first round which makes them available for use in subsequent rounds rather than submitting the woman to repeated extraction processes if the first round is unsuccessful; and 5) when the donors no longer have any use for the embryos not implanted (Manninen, 2007). The surplus embryos are a reality of IVF and they can be donated for research with consent of the donors; embryos not donated are destroyed when no longer needed (Bobbert, 2006; Borghese, 2007; Camporesi, 2007; Manninen, 2007; Wainright, et al., 2006). PGD is offered to couples at risk of having a child with serious genetic defects, or in some cases, to women with multiple miscarriages due to abnormal chromosomal arrangements. PGD embryos with defective chromosomal arrangements or defects are viewed as being "biologically dysfunctional" and therefore are considered by scientists as being unsuitable for implantation and will be subsequently destroyed. Because of this, many scientists do not view PGD embryos as having the same ethical "baggage" as IVF, and therefore, see no problem with using them for stem cell research (Wainright, et al., 2006).

Embryonic stem cells, in the absence of any specific differentiation conditions, will maintain their self-renewal capabilities for an indefinite period of time (Kim, et al., 2005) and can be harvested in two different ways. One way is via the previously mentioned IVF procedure. The other way is through a process called somatic cell nuclear transfer (SCNT). SCNT is the same process that was used to produce the sheep named "Dolly" (Scott, 2006). This process involves the removal of the nucleus of two different cells: a somatic cell and an egg cell. Once that is accomplished, then the nucleus of a somatic cell is inserted into the now empty egg cell. This results in a genetically identical copy, or a clone, of the somatic cell (Scott, 2006). This has proved to be a useful technique in producing genetically identical tissues of the donor/patient and for producing the human embryonic stem cell (hES) lines (Rajasekhar, et al., 2005; Wainwright, et al., 2006). As of 2006, there were an estimated 414 hES lines available (Guhr, Krutz, Friedgen, Loser, 2006; Scott, 2006) established in at least 20 countries. However, according to Guhr, et al., (2006) not all these lines are clearly pluripotent and there has been limited characterization of these cell lines. In 2006, there were 67 hES lines eligible for embryonic stem cell research (Yu & Thomson, 2010). As recently as April 14, 2011, there were 91 hES lines registered in the National Institutes of Health (NIH) Registry eligible for embryonic stem cell research. Progress in stem cell research has been hindered by two pervasive problems: 1) the inability to produce these various stem cells types (lines) in sufficient quantities; and 2) the lack of methodology to derive the differentiated cells from stem cells in a predictable manner (Rajasekhar, et al., 2005).

Adult stem cells can be harvested after development from almost every other cell type in the body. Research involving adult stem cells is without the controversy that surrounds embryonic stem cell research. However, adult stem cells are difficult to find in some tissues/organs and do not exist *in vitro* as long as human embryonic cells do (Watt & Hogan, 2000), nor are they as potent as embryonic stem cells. In addition, it has also been shown that almost every time adult stem cells have been transplanted back into the desired animal tissue, this tissue has developed teratomas (cancer) (Scott, 2006).

Stem Cell Therapies

Stem cells show potential for curing diseases. In fact, stem cell therapy is one of the ideal means to cure almost all human disease known to man (Jung, 2009). Stem cell research has shown that stem cells can replace abnormal or dead cells with normal cells from a human stem cell line and eventually change the paradigm of medical practices.

Stem cell therapy has actually been practiced for a number of years using human adult stem cells for bone marrow transplants in leukemia patients. Many scientists believe that Parkinson's disease, spinal cord injuries, and Type I diabetes patients will be candidates for embryonic stem cell therapy when these diseases are treated in their earliest stages (Jung, 2009). The U.S. Food and Drug Administration (FDA) has already approved clinical trials using the products of human embryonic stem cells for patients with acute spinal injuries (Jung, 2009). Human stem cell research has also been shown to be a successful alternative for testing the efficacy and safety of drugs or other medical treatments on cells or tissues that have been derived from stem cells. By using specific cells in testing that are targets of a new drug, the results of the tests may be more reliable (Jung, 2009; Kim, et al., 2005).

Stem Cell Controversy

There has been much public debate regarding research on embryonic stem cells versus adult stem cells, as well as, many arguments and disagreements about policies that need to be in place regarding stem cell research. On March 9, 2009, President Barack Obama overturned President Bush's ban on research using embryonic stem cells and the use of taxpayer funds to do research in which embryos are created or destroyed. President Obama (2009) made the statement that "science—not political ideology—would guide his administration". He also reversed the limits on federally funded stem cell research. As a result, researchers can now propagate newer, healthier, and better cell lines. However, according to the law, they may not create human clones (Obama, 2009).

Scientists disagree as to when an organism is actually considered to be viable (alive). Some scientists suggest that life begins at fertilization; others say it can only be considered as being alive when it has been shown conclusively that the successful fusion of two gametes resulted in viable offspring. Some scientists claim that an embryo is just a collection of cells and that eight cells in a dish do not represent a living person (Wainright, et al., 2006). Another group of scientists argue that life doesn't begin unless the fertilized egg has been implanted, whether by natural pregnancy or IVF, and not until about 14 days post-fertilization when neural development has been signaled (Jung, 2009).

The media often blurs the lines between scientific findings regarding stem cells with people's opinions about the ethics and moral issues surrounding these findings. In addition, according to Crandraft and Bybee (2004), "peoples of many cultures obtain their knowledge of the world from religiously inspired texts, from charismatic and inspirational leaders, or from mythical folklore, and although such knowledge is crucially important to people as they form spiritual, ethical and moral views of the world, it is an inadequate basis for promoting human well-being and prosperity" (p.1). This quite possibly contributes to the alternative conceptions and strong opinions that some people have regarding stem cells despite their lack of correct scientific background/facts regarding these topics. In fact, some researchers express extreme frustration with (mis) understandings and the apparent lack of awareness the public has concerning the very strict regulations that scientists/researchers are constrained by in terms of experiments utilizing animals, human tissue, and stem cells (Wainright, et al., 2006).

In a typical tenth grade biology classroom most teachers do not elaborate on or provide much if any instruction on stem cells. Instructors may not be educated in stem cells. Hashweh (1987) says that when instructors are planning instruction they tend to delete details they themselves do not understand. Additionally, textbooks generally do not devote more than half a page to the topic of stem cells. This is probably because it is not specifically outlined in the National Science Standards or any state standards at the time of the study. The National Science Standards were last updated in 1996, while the California State Standards were last updated in 1998 (not slated for review and/or updating until 2013-2014)(National Science Standards, 1996; CDE, 1998). Since the publication of these documents, there have been a number of important scientific advancements in the field of stem cell research. Yet, stem cell research is a controversial topic and as Plagge's (2008) study found, people have strong opinions about stem cell research even though they don't have a scientific understanding of stem cells. Unfortunately, opinion that is not based on scientific fact can be detrimental to future advancements in the field of stem cell research, limiting the potential to save lives by curing disease, healing wounds, and altering devastating genetic traits. High school students are one day going to be voting and making decisions about current scientific endeavors and it is our responsibility as educators to make sure they are prepared to make those decisions based on scientific fact. In addition to the cellular biology they are currently taught, students should also be taught where stem cells are found, how they are harvested, the different types of stem cells and which stem cells are currently viable for curing diseases and saving lives and which ones may be problematic and carry a cancer risk. There are few topics like stem cells that also provide the opportunity for students to explore the important biological concepts associated with cells and relate them to stem cells, as well as, explore ethical and social controversies. In order for students to develop a deep understanding of stem cell issues, instructors should know what conceptions students already hold so that curricula can begin with that as a starting point and build on that knowledge. This study will add to the relatively few studies regarding stem cells and stem cell research that explore alternative concepts high school students have and attempt to analyze the prevalence of alternative conceptions held by high school.

Alternative conceptions, defined as scientific ideas an individual has that are not in alignment with current scientific understandings, have been studied quite extensively over the past three decades. However, there are no definitive tools developed as of yet that specifically identify alternative conceptions in science topic areas at the high school level. The most common method of researching alternative conceptions is through qualitative interviews, while the second most common method is through multiple choice tests (Wandersee &Mintzes, 1987). Qualitative interviews allow for the analysis of individual responses for the discovery of alternative conceptions or scientifically correct understandings (Driver, 1994). Interviews have the advantage over multiple choice tests by allowing the investigator to determine if the interviewee understands the topic or just has superficial knowledge. Multiple choice tests are able to assess student's knowledge on a topic, but do not accurately demonstrate a student's understanding of a topic. According to Wiggins and McTighe (1998) students must not only possess rudimentary knowledge, but must also be able to explain, interpret, and apply that knowledge, as well as have perspective on the information, possess self-knowledge of their understanding, and empathize with the understandings held by others. Qualitative interviews are an excellent instrument to determine whether students hold scientifically correct understandings or alternative conceptions. According to Driver (1994), interviews allow for a more in-depth look at individual students' explanations of scientific phenomena by probing and prodding student ideas much more extensively than any paper-pencil assessment ever could. The insight provided in interviews, such as those conducted in this study on stem cells, helps demonstrate areas that are conceptually difficult for students to understand, providing a basis for curricular instruction.

Research Question

What are the alternative conceptions held by high school students regarding stem cells and stem cell research?

Methodology

Exploratory Design Approach

This study followed a qualitative exploratory approach involving the collection, analysis, and interpretation of qualitative data (See Figure 1). I utilized the qualitative approach in this study to gain insight into the conceptions high school students hold regarding stem cells and stem cell research. I was most interested in gaining insight into the participants' knowledge about stem cells, specifically embryonic and adult stem cells, as well as, stem cell research. I was also interested in whether or not the participants' knowledge was scientifically correct or included alternative conceptions.

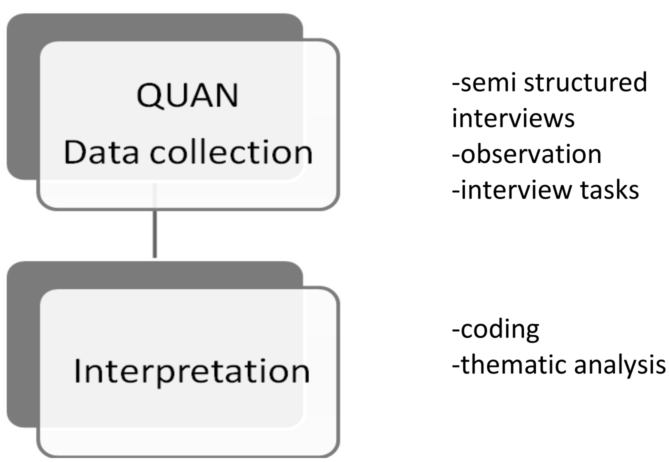


Figure 1. Exploratory design approach

Setting and Participants

The participants in the study were high school students attending an urban public school in southern California. The high school had earned an Academic Performance Index (API) of 792 at the time of this study. The site's ethnicity breakdown was 5.78% African-American, 0.74% American Indian, 2.54% Asian, 33.22% Hispanic or Latino, 0.35% Pacific Islander, and 56.31% Caucasian. Six percent of the population qualified for English Language learner support; 9% of the student population is in special education and 40% qualified for free or reduced price lunch. Based upon the last official report, the graduation rate for the 2008/2009 academic year was 93.2% with 93.2% passing the CAHSEE (California Academic High School Exit Examination). The science departments' student-to-teacher ratio was 30:1; which has culminated in 60% of science students achieving a passing score of "Proficient" or "Advanced" on the state science standards tests (STAR). The percentages of students achieving "Proficient" or "Advanced" on California's high stakes standardized STAR test by group are summed in Table 1 below.

From the school's population of 2559 students, thirty-seven volunteers were chosen as the sample for this study. Approximately 150 students expressed an interest of participating in this study. Each of them was given a "Consent to Participate" form (Appendix A). The first 37 students to turn in the forms were selected to participate in the order received. Since all volunteers were between the ages of 15 and 19, they were also requested to have their parents fill out and return a "Parental Assent" form (Appendix B). All but five of the 37 volunteers were concurrently enrolled in biology. The remaining five had successfully completed biology the previous year. The interviews took place in a science classroom at Serrano High School and were 30 minutes to 1 hour in duration. Students were not compensated in any way for volunteering and participating in the interviews.

Table 1. Summary of STAR results Serrano High School.

STAR results-Subgroups
Percentage of Student's Scoring Proficient & Advanced Levels
2009/2010

	SJUSD	Serrano High School				
	All	Male	Female	English Learners	Economically disadvantaged	Students with disabilities
Science	60	66	57	16	52	19

Interview Protocol

The interview required interaction between the researcher and participants utilizing one-on-one, semi-structured, open-ended questions which were previously developed and used in a pilot study. Interviews were audio taped and videotaped in order to accurately transcribe the interviews. Each interview followed the sequence of questions shown in Table 2. Additionally, follow up questions were asked of students if their answers were unclear or further clarification was needed. During the interviews, I attempted to identify and note whether or not the student guessed in her responses, or whether she could present justification for her answer. Some students were forthcoming with saying that they were guessing at their responses, others were asked if they were guessing when their tone in response to a question suggested that they were unsure. I also took notes as to whether the interviewee provided some scientifically correct justification, or if her answers were completely scientifically correct. Verbatim transcripts of all 37 one-on-one interviews were prepared (approximately 104 hours) and were then analyzed to obtain a preliminary taxonomic scheme of students' alternative conceptions regarding stem cells.

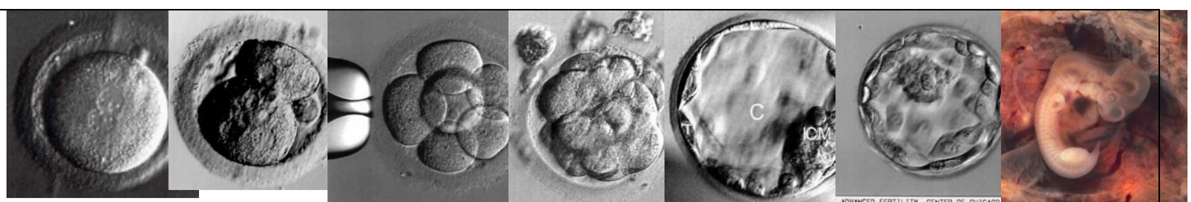
Table 2. Interview Questions

1. How would you describe a cell?
    a. Can you draw me a cell with appropriate organelles?
2. The body is made of trillions of cells.
    a. Are all the cells pretty much the same, or do cells differ?
    b. What are some of the characteristics that distinguish one cell type from another?
    c. Do all cells divide in the same manner? If not, how do they differ?
3. What does it mean when we say "a cell differentiates?" What and how do cells differentiate?
4. What is an embryo? How is it related to a zygote? To a fetus?
    a. What is the time frame between all three of these stages?
5. What do you know about stem cells?
6. Have you ever heard of embryonic stem cells?
    a. What have you heard or what do you know about them?
7. Have you ever heard of adult stem cells?
    a. What have you heard or what do you know about them?
    b. Where can you find adult stem cells?
8. Do you know how embryonic stem cells differ from adult stem cells?
    a. Where can you find embryonic stem cells?
9. Do you know what happens at an IVF clinic?
    a. Do you know what happens to embryos following IVF after couples no longer need or want remaining embryos?
10. Have you heard of the sheep "Dolly"?
    a. Do you know how Dolly was created?
    b. Do you have any idea why the creation of Dolly was so significant to the field of genetic engineering?
11. Do you know what cloning is?

Interview Tasks

All interviews began with the question "How would you describe a cell?" Next, students were asked to diagram a cell with appropriate organelles and give an oral description of each. It was known that all interviewees had received prior instruction in either 7th and/or 10th grade in cells, cell structure and function. Therefore, this question was meant to make the student more comfortable with the interview process and ease them into the more difficult questions.

A second interview task utilized photographs of embryological developmental stages zygote through 9-week-old embryo. See Figure 2 for photographs. The photographs were separated and mixed up, and then students were asked to put the photographs in the correct order of embryological development. Along with notating the order in which the students placed the photographs, notations were also made as to whether or not the student was able to complete the task and/or if the student was hesitant or confident when arranging the cards during the card sort and whether they were pausing, revising, and refining their choices. I also noted if the participants could justify their responses without prompting.



Day 1	**Day 2**	**Day 3/8**	**Day 4**	**Day 5**	**Day 6**	**Week 9**
Oocyte		**6 Cells**	**Morula**	**Intercellular Mass**	**Blastocyst**	**Embryo**

Figure 2. Interview Task
Photographs Demonstrating Embryo's in Various Stages of Development.
Photographs 1-6 courtesy of www.advancedfertility.com and Photograph 7 by Ed Uthman, MD. Placed in the public domain and originally posted to the Web on 12 Oct 2001

Data Analysis-Coding

Coding of transcripts was developed based upon emergent stem cell conceptions held by high school students, rather than *a priori*. Themes were identified based upon the coding of interviewee responses, which happened to also align with the series of 11 concept questions. Passages of interviewee responses were coded into the appropriate theme and analyzed. Alternative and naïve conceptions were identified further organized within the following 12 themes:

- Distinguishing cell characteristics
- Differentiation
- Embryos
- Stages of embryological development
- Embryonic stem cells
- Embryonic stem cell location
- Adult stem cells
- Adult stem cell location
- Differences between embryonic and adult stem cells
- *In Vitro* fertilization (IVF)
- Excess embryos left over following IVF
- Cloning

Interviewee responses (passages and applicable segments of passages) were coded on a scale I created of “0” to “2”; a “2” representing a scientifically accurate concept, “1” was assigned when an alternative or naïve concept was identified. A “0” was assigned when no answer or an off topic answer was provided. Coded responses were then organized into one of the above 12 themes listed. In most cases, concepts organized by theme were those that were held by 8-10% or more of the student population. However, I have also listed the naïve conceptions that only a few individual students offered when it appeared they were earnest and not just guessing. Thematic tables will be discussed in the analysis. See Table 3 for an example of responses and coding to the question "Where are embryonic stem cells found?"

Table 3. Example of coding: The numbers 1-10 are 10 interview responses to the question "where can embryonic stem cells be found?" The far right column provides the coding score for each response. See coding key in table 3 below.

Question: Where are embryonic stem cells found?	
Interviewee Responses	Codes
1. In the blastocyst and the embryo	*2*
2. Embryonic stem cells are derived from the embryos.	*2*
3. They are found in the embryo, not bone.	*2*
4. In an aborted baby.	*1*
5. In the umbilical cord.	*1*
6. In fetuses.	*1*
7. All over the body.	*1*
8. In the embryos brain stem.	*1*
9. In the embryos bone marrow.	*1*
10. I have no idea.	*0*
Coding Key: 0=answer not provided; incorrect or off topic 1=Alternative or naïve concept 2=Scientifically correct concept	

Following the coding of the data, I looked at each piece of data independently and compared it to other pieces of data from the same interviewee; looking for any similarities or differences. This inductive methodology of analyzing the data permitted a more thorough examination of all ideas and meaning that may exist within the data (Cresswell, 1998).

Analysis of Interviews

Structure and Function of the Cell

All interviews began with the question “How would you describe a cell?” Almost all students (94%) were able to describe the cell as “the basic unit of life”. The remaining six percent of the students demonstrated a more naïve view of cells and were unable to accurately describe a cell. For example, one student replied that a cell is a “microscopic thing that makes up an organism” and another described the cell as the “smallest living component of an organism”. One hundred percent of the students were able to successfully make a diagram of a cell and label the appropriate structures, as well as, verbally give an accurate description of each organelle, as well as their structure and function.

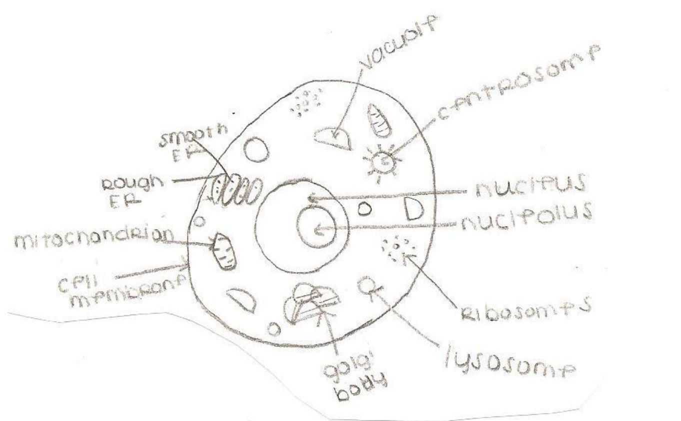


Figure 3. Example of student cell diagram

When students were asked about the similarities and differences in cells and cellular division students (57%) suggested that there is a diversity of cell types and that cells do divide differently; either through mitosis, meiosis, or binary fission. Eight of these 21 students (21% of all students) stated that there are both “prokaryotic and eukaryotic cells" and added that this means that the structure of the different cells are different and subsequently so is the cells' function. Another eight of these 21 students further stated that there are different cells in our body (i.e., "sex cells and body cells") and that each of those cells "divides differently". Two students pointed out that different cells (e.g., neurons, cardiac, animal, plant, sperm, egg, cancer) are located in different organisms (e.g., plants, animals, bacteria). These two students also stated that and there are structural differences in cells (e.g., genes, ions, proteins) and that the cells are located in different tissue (e.g., nervous, cardiac, epithelial). They concluded by stating that because of this, cells divide differently (e.g., meiosis, mitosis) and at different rates (e.g., cancer cells will divide rapidly and indefinitely without checkpoints). Sixteen additional students (43% of all students) stated that they think all cells divide the same way. Two of those students specifically stated that "all cells are pretty much the same and do the same thing". One student stated that he thought cells "do not divide differently; they instead divide at different speeds depending upon where they are". Another student stated that he thought that "cells divide differently based upon their shape". See Table 4 for a summary of this data.

Table 4. Distinguishing Cell Characteristics.

Scientific Concept	**Naïve and Alternative Conceptions Obtained from Interviews**
The cell is the basic unit of life. A group of cells working together will form tissues. There are two kinds of cells recognized in all living organisms: prokaryotic and eukaryotic. The basic structure of all cells, whether prokaryotic or eukaryotic, is the same. However, function will vary. Some organisms are unicellular. Other organisms are multicellular and are made up of a number of different cells with different functions (e.g., sperm cells, egg cells, nerve cells, bone cells)	• The cell is a microscopic thing that makes up an organism. • The cell is the smallest living component of an organism. • Cells all divide the same way. • All cells are pretty much the same and do the same thing. • Cells do not divide differently; they instead divide at different speeds depending upon where they are. • Cells divide differently based upon their shape.

When asked about the differentiation of cells (Table 5), many students (32% of all students) indicated that they didn't understand what was meant by differentiation; however, a few students (11% of all students) ventured to guess that it meant that the cells were different or became different somehow. The majority (65%) of students were able to correctly explain differentiation. One student explained that "one cell may change or mature into whatever tissue it must form. Organelles that are needed grow or develop more, or unnecessary cells shrink". No one could explain what happens once a cell differentiates; that it becomes "committed" to its fate. Two students (5% of all students) mentioned that cells differentiate using selective gene expression. For example, one of them explained that the cell was “expressing different genes in the cells to do different things”.

Table 5. Cell Differentiation.

Scientific Concept	**Naïve and Alternative Conceptions Obtained from Interviews**
Process of a cell becoming more specialized. Groups of specialized cells may form tissues in the multicellular organism. Changes are due to gene expression. These changes may change a cell’s size, shape and function. Adult and embryonic stem cells both change into other cell types. Adult stem cells differentiate to repair tissue and replace worn out cells. Embryonic cells may be pluripotent, totipotent, or multipotent.	• One cell may change/mature into whatever tissue it must form. Organelles that are needed grow or develop more or unnecessary cells shrink.

Embryos

When students were asked the question “What is an embryo?” there were a large number of different answers. Most students (68%) correctly expressed the idea that embryos were formed from the zygote during the first cellular divisions and represented a developing stage of an organism. The remainder of students either could not describe an embryo at all or in their response demonstrated a lack of understanding of what an embryo is. For example, the following responses were recorded for three students (9%) describing an embryo: “the start of a baby before the sperm connects with it”, “it is a developing zygote; it is a zygote”, an “embryo is an immature egg” (see Table 6).

Table 6 "What is an embryo?"

Scientific Concept	Naïve and Alternative Conceptions Obtained from Interviews
Stage beginning with first mitotic divisions of zygote. Developing organism from conception to implantation (first seven or eight weeks). Includes blastula, gastrula, and organogenesis stages of embryonic development.	• An embryo is an immature egg. • The start of a baby before the sperm connects with it. • An underdeveloped animal. • It is a developing zygote/it's a zygote. • I heard of it mostly in reproductive terms that an embryo is what is in the female when the sperm goes into the female and fertilizes the egg.

Embryological Development

The majority of students interviewed (70%) were able to correctly identify that a zygote was the result of the fusion of a sperm and egg cell. The same 70% of students were also able to correctly identify the embryonic path of development from an embryo, to a fetus, to a baby. Approximately 21% of the students stated that they had no idea what an embryo or a fetus was and were unable to answer the question. The following statements were recorded from a few students (9%) regarding the stages of embryonic development: a "zygote is before the egg is fertilized", "an embryo forms a zygote, then a fetus", and "the embryo is when you can start seeing it on an ultrasound".

Many students (73%) appeared to have a lot of difficulty with accurately stating the time frame between a zygote, embryo and fetal development. Answers ranged anywhere from a few days, to a few weeks, to a few months, and to nine months to go through all three stages. A few students (11%) expressed that it took anywhere from 1-4 weeks for the zygote, 4-9 weeks for the embryo, and then the remainder of the entire nine month time frame was spent as a fetus. Table 7 provides a summary of this data.

Table 7. Stages of Embryological Development.

Scientific Concept	Naïve and Alternative Conceptions Obtained from Interviews
Fertilization leads to a zygote. The zygote then begins cellular division: Day 1: first cleavage (two cells). Day 2: second cleavage (four cells). Day 3: 6-12 cells (can test for genetic diseases if IVF is done). Blastocyst Day 4: morula. A solid ball of 16-32 cells. Day 5: solid morula becomes a hollow, fluid-filled blastula. ICM forms the embryo. Implantation in uterine wall. Day 6-7: blastocyst attaches to endometrium. Day 7-10: gastrulation (formation of germ layers). Embryo (week 3-8). Fetus (week 9 till birth).	• A zygote is before the egg is fertilized. • An embryo forms a zygote, then a fetus. • The embryo is when you can start seeing the baby on an ultrasound. • 1-4 weeks for the zygote. • 4-9 weeks for the embryo.

Order of Embryological Development

Almost half (47%) of the students were able to place the photographs (see Figure 2/Appendix D) of embryos in various stages of embryological development in the correct order. Thirty-five percent of the students who placed the photographs in an incorrect order had mixed up pictures 4 and 5. Each of these students stated that the reason is that "pictures 4 and 5 look very similar" and since they had never seen it before, they thought picture 4 looked more complex (i.e., has more cells) than picture 5. Eleven percent of the students mixed up pictures 6, 5 and 4. Each of these last two groups of students stated that they couldn't tell by the pictures which one showed a more complex level of development. Three students (8%) mixed up pictures 1 and 2. One student could not decide where photo 6 went in the order. He said it "didn't seem to fit into the scheme of things".

Stem Cells

When students were asked "What do you know about stem cells?" a large number of responses were offered. Students either had no idea (24% of all students) what stem cells were, or were unable to provide some kind of description of where they thought the stem cells could be found. The majority of students (68%) who did provide an explanation, showed that they at least had a vague idea of stem cells and where they could be found, as well as, what they could do. For example, one student stated that "stem cells are undifferentiated cells from blood or tissue of newborn baby that have the ability to cure diseases", while another stated that stem cells are "unspecialized cells that give rise to one or more types of specialized cells". One student stated that "stem cells are part of the nervous system and are located in the spinal cord", while another said "stem cells reside in your bones and produce all other cells for the body for treatment of some cancers via stem cell transplant".

Embryonic stem cells

The majority of students (76%) stated that they had heard of embryonic stem cells. However, 79% of the students were unable to indicate specifically where embryonic stem cells are found. Several students (14%) ventured a guess and said that embryonic stem cells are "found in the embryo", but were unable to give any further description of a specific location. One student stated that embryonic stem cells are "developing in the nervous system in the baby; in the womb". Several students (11%) suggested that embryonic stem cells are found in the umbilical cord and in the fluid within the umbilical cord, which could be saved since it is full of embryonic stem cells. One student stated that stem cells were “not in the bone; they [were] in the brain stem”. Only one student correctly answered that “they are found in the blastocyst”. The remainder had no idea and did not supply an answer. See Tables 8 and 9 for a summary of embryonic stem cell conceptions.

Table 8. Embryonic Stem Cells

Scientific Concept	Naïve and Alternative Conceptions Obtained from Interviews
Unspecialized cells found in the inner cellular mass of a blastocyst at 4-6 days post- fertilization. Usually derived from embryos that have been fertilized *in vitro* and donated for research. Embryonic stem cells have the potential to differentiate into any of the 200 various kinds of cells known in the body (Pluripotent).	• Found in the embryo. • Develop in the nervous system in the baby, in the womb. • Found in the umbilical cord and in the fluid within the umbilical cord, which could be saved since it is full of embryonic stem cells. • Not found in the bone; they were in the brain stem.

Table 9. Embryonic Stem Cells and their Location.

Scientific Concept	Naïve and Alternative Conceptions Obtained from Interviews
Embryonic stem cells are isolated from the inner cellular mass of a blastocyst; approximately 4-6 days following fertilization. Blastocysts are created from a fertilized egg/zygote or from therapeutic stem cell cloning.	• Come from umbilical cords and can later be used for stem cell transplants to cure cancers such as leukemia (or they are the first cells forming zygotes). • They come from potential babies. • They come from the umbilical cord of an embryo; either an aborted one or after it is born. The fluid containing the stem cells is saved. • They are cells developing in the nervous system in the baby in the womb. • They come from aborted babies. • In the back of the brain. • In the ovaries. • In umbilical cords. • All over the body. • The embryos' brain stem or bone marrow.

Adult stem cells

A little more than half the students interviewed (57%), stated that they had heard of adult stem cells. When questioned further, a number of students in this group (11% of all students) said that adult stem cells are found in the "spinal cord". One student stated that the adult stems cells are "removed from the pelvic bone" and another said they are found in the "brain stem". A couple students (13%) said that they are found in the "bone marrow of fully developed humans". Forty-six percent could not explain where adult stem cells are found. A couple students (8%) ventured a guess and said “in adults”. See Tables 10 and 11 for a summary of adult stem cell conceptions.

Table 10: Adult Stem Cells

Scientific Concept	Naïve and Alternative Conceptions Obtained from Interviews
Undifferentiated cell that can be found among other differentiated cells and is able to renew itself and differentiate to become a specialized cell making up a tissue or organ.	• They are mature cells that can serve to become different types of cells. • They can function as any type of cells. • They are older in age?

Table 11. Adult Stem Cells and their Location.

Scientific Concept	Naïve and Alternative Conceptions Obtained from Interviews
Adult stem cells, previously thought to be difficult to find, have been found in almost every tissue in the human body. They undergo mitotic division to replace damaged or dead cells.	• In a developed embryo. • In adults. • In the spinal cord.

Embryonic vs. Adult Stem Cells (a comparison)

When students were asked if they could explain the difference between embryonic and adult stem cells, 70% of the students stated that they had “no idea”. One student said that “adult stem cells are able to differentiate into different types of cells”, while another student said that “one is from animals and one is for humans”. Still another student guessed that “maybe it’s the time they take to become stem cells?” See Table 12 for alternative conceptions.

Table 12. The Differences between Embryonic and Adult Stem Cells.

Scientific Concept	Naïve and Alternative Conceptions Obtained from Interviews
Differ in the number and type of differentiated cells they can become. a) Embryonic stem cells are referred to as being pluripotent due to the fact they have the ability to differentiate into all the body cell types. b) Adult stem cells are limited to differentiating into the cell types they originated from. c) Embryonic stem cells can be grown in the laboratory in culture. d) Adult stem cells were previously thought to be difficult to locate in mature human tissues and difficult to culture. During the last twelve months scientists have disproven this. Adult stem cells have been used for decades in bone marrow transplants. e) Embryonic stem cells maybe too unspecialized to control without some modification. (Fetal cells have been transplanted, but have shown they may possibly give rise to cancer).	• Maybe the time they take to become stem cells? • Just age, I guess? • Embryonic cells are immature, while adult cells have fully developed. • One is for animals and one is for humans. • Adult stem cells are able to differentiate into different types of cells. • Embryonic stem cells could help to replace organs. • One comes from babies, while the other comes from adults.

***In vitro* Fertilization and Embryos**

A large percentage (57%) of students did not know what an *in vitro* fertilization (IVF) is or how it is performed. One student guessed that it had something to do with "abortion", while another indicated that "embryos were destroyed to extract the cells for IVF". Two students mentioned "Octomom" (Nadya Suleman) and that her doctor

(Michael Kamrava) had “implanted too many embryos and she gave birth to eight babies”. Two students had vague ideas about the process of “*in vitro* fertilization”: one stating that “ova were removed, fertilized with sperm and implanted into the uterus of a female”.

Forty-six percent of the students did not have any idea what was done with the excess embryos following “*in vitro* fertilization” procedures. A couple (5%) ventured to guess that it had something to do with abortion or that the left over embryos would be used for stem cells. The rest of the students (49%) stated that they thought the “embryos would die, be disposed of, frozen, used for scientific research, or that they would be donated to someone else in need”. See Table 13 and 14 for a summary of this data.

Table 13. In Vitro Fertilization

Scientific Concept	**Naïve and Alternative Conceptions Obtained from Interviews**
In vitro fertilization is a procedure utilized in fertility clinics that enable infertile couples to have eggs removed from a female’s body and subsequently be fertilized in a glass dish in the laboratory. A few of the healthy embryos are implanted in the female’s uterus.	• Mature ova are cultured and developed into embryos. • Sperm is donated and it depends on whether there is an embryo or not. Sperm is injected into the embryo to get the fertilized egg. For example in the Octomom case, the doctor put too many in and there were too many embryos. • They take stem cells from the embryo? • They fertilize a moms’ egg with the preferred new stem cells. • They give the woman a drug so she becomes more fertile, then they inject eggs into her.

Table 14. IVF and the Fate of Excess Embryos.

Scientific Concept	**Naïve and Alternative Conceptions Obtained from Interviews**
Excess embryos are deep frozen in liquid nitrogen (cryopreservation). Excess embryo's may: -lose viability during freezing process, thawing procedure, some kind of malfunction or operator error. –be used in second attempt to conceive. –be donated to couples unrelated and unable to conceive ("snowflake babies"). Excess embryos that are not preserved, are often flushed down sink drain while alive, or are discarded, destroyed, incinerated, exposed to dry air, donated to research and experimentation, training, diagnostic purposes, etcetera. Approximately 8% (11,000) of all embryos are actually used in research; the rest are destroyed.	• Abortion.

Cloning

Students were asked if they "know what cloning is?" Seventy-three percent of the students were able to explain that cloning was producing a genetically identical organism; however, they were unable to describe the process of cloning when questioned further. In fact, only one student was able to accurately describe the process of cloning: "Cloning is removing the nucleus from egg cell and adding it to a somatic donor cell, growing it in culture to produce embryos and then they implant the embryo in a surrogate mother".

To further probe students' understanding, the students were asked if they had heard of the cloned sheep named "Dolly". The majority of students (84%) said that they had heard of Dolly and stated that "she was the first successfully cloned animal". When asked if they knew how Dolly was cloned, only one student (the same student as in above paragraph) identified the process of "somatic cell nuclear transfer" and gave a description of the process (see above paragraph). The remaining students (97%) were unable to explain how the cloning of Dolly took place, though one student did make an ethical statement that "cloning is not stable; it is like playing God". See Table 15 below for a summary.

Table 15. Cloning.

Scientific Concept	**Naïve and Alternative Conceptions Obtained from Interviews**
Nucleus of unfertilized ova is removed and replaced by the nucleus of a body cell from an existing organism. The ovum is induced to grow and develop into an embryo. Reproductive cloning: clone is implanted into female uterus and carried to term. Therapeutic cloning: cells from the inner cellular mass will be removed in days 5-7 and the embryo will be destroyed in the process.	• Cloning is extracting DNA, replicating it, inserting into an egg and letting it develop. • Growing an embryo from stem cells and then implanting them into a female organism. • It is when a somatic cell is added from a cell is added from a donor and the cell grows to produce embryo and makes a clone. • Making copies of babies. • It is when a human is made from the cells of another. • Where they make the exact opposite of something.

Conclusion

General Findings and Themes

The goal of this study was to identify the existence and prevalence of alternative conceptions that are held by high school students regarding stem cells and to subsequently develop a classification (taxonomic) scheme of these alternative conceptions. Student drawings and semi-structured, open-ended interviews were used to probe student's understanding of cellular concepts and subsequently stem cell concepts. Alternative conceptions were identified and classified. My interviews revealed that students held naïve conceptions in almost every question and topic covered in the interviews despite no formal instruction on the topic. Some naïve concepts were held by individuals, others were held by several students. For most cases it seemed that either the students didn't know the answers, ventured a guess at their response to the questions, or had some unique idea about the concept asked. In some cases, it seemed that the students were unable to, or at least were having some difficulty, expressing or explaining ideas in regards to stem cells. It is also possible that students may have been responding to the interview questions just to supply an answer, rather than providing an accurate representation of what they really do or do not know. For example, some students claimed that "cells all divide the same way", however, based on their responses it was difficult to determine whether they were basing this on their opinion or whether they indeed believed this was the scientific fact. This unexpected phenomenon repeated itself regardless of the number of students I interviewed.

Normally, qualitative research involves gathering large amounts of information from a few interviewees; however, by the end of this study I had interviewed a total of 37 students. This was largely due to the fact that the data collected along the way appeared to be inadequate or inconclusive for developing a scheme of alternative conceptions because, as stated previously, new naïve conceptions kept appearing. In fact, in response to each question there were a large number of contradictions and few consistencies within individual students. Therefore, the strategy to increase the number of interviewees to help clarify thematic categories of student conceptions did not, in the end, provide additional analytic insight.

Although there was not a clear trend in naïve or alternative conceptions, organizing them into themes revealed during the interviews by stem cell topic (see compilation of individual tables of themes, including students naïve or alternative concepts in Appendix E), helped to expose conceptual (mis)understandings that students held. The list of student conceptions is rather extensive; revealing that high school students have a lot to learn about stem cell related concepts.

Although there were challenges synthesizing the interview data, student interviews appeared to be an effective method for probing some aspects of learning difficulties with cells and other related complex topics. For example, I initially chose to open the interviews with a drawing activity that I thought the students would be successful with and to put them at ease with the interview process. It has been shown in previous studies (Köse, 2008) that drawings can also be used to probe a students' understanding of science topics and to explore their ideas about abstract concepts. This study concurred with those findings and showed that students can demonstrate what they know and understand about cells and their organelles through drawings (the cell diagrams). Students were asked to draw a cell, include organelles, and to orally give a synopsis of their chosen cell and its organelles. Interestingly, every student drew an animal cell and could accurately diagram and describe the functions of the appropriate organelles. In analyzing the diagrams directly and independently of other data collected, one might conclude that the students had a conceptual understanding of animal cells and their organelles, as well as, their structure and function. However, when analyzing holistically all data collected, it becomes apparent that there were a number of inconsistencies between what the students initially drew and explained (about the cell) and their later responses. For example, a large population of students in this study verbally stated that all cells are the same and all cells function and divide the same way. This suggests that maybe there is a hidden reason (that could be investigated in future research) that all the students drew basically the same animal cell and verbally gave the same responses. However, the data shows that students do not have a complete understanding of variations in cells (e.g., structure, function and division) as initially concluded, and instead have resorted to memorizing discrete units of information. The data collected also suggests that the students' animal drawings appeared to be duplications of previous instruction (i.e., most teachers ask their students to make diagrams of the animal and plant cell; including organelles and their functions) and that students have difficulty making connections with what they know about the animal cell to other cells and cellular processes.

Student's Stem Cell Understanding was Superficial

The abundance of naïve conceptions students presented in this study may be due to the fact that cells are often complex, foreign, and are associated with other abstract concepts that students struggle to imagine or understand (e.g., cell cycle, differentiation).

Other studies have confirmed that students do indeed struggle to visualize what the textbook and their instructor(s) are attempting to describe for them (Woolfolk, 2001). It follows then that instruction should include models, hands-on activities, pictures, computer images, and other realia so that students can have an opportunity to visualize and grasp abstract concepts (Woolfolk, 2001).

When students were asked if they could tell me more about a particular stem cell topic, many students were able to supply an answer, but were unable to explain further what they meant or to make connections between what they knew about cells and stem cell topics. For example, many students said that it was "wrong" to use embryos in stem cell research. However, when they were asked to explain further about why using embryos in research was wrong, there appeared to be a disconnect between what the students previously demonstrated they knew about embryos, how those embryos are used in research, and specifically the fact that embryo's are destroyed in research. These findings reveal that students were unable to make connections between what they know about cells in general and the concepts related to stem cells, including the inability to establish any other connections associated with stem cells; such as how the stem cells develop, how stem cells are harvested, and what happens with the excess embryos.

This study also showed that students have conceptual difficulties with explaining cellular phenomena including cellular organization, cell differentiation, cloning, *in vitro* fertilization, and embryological development. It is likely that in order to understand stem cells, these related subordinate concepts must first be mastered. For example, the majority of the students could not establish accurate relationships between embryological development and cell differentiation.

Conflicting Ethical and Concept Knowledge

Plagge's (2008) analysis of college student stem cell knowledge, showed that despite the fact that students do not know much about stem cells they have strong opinions regarding the use of stem cells. This current study confirms that finding. For example, one student who stated that "God should decide who is born or not" also stated that scientists should use "leftover embryos because then their existence would not be wasted". In other words, the student thought only God should decide who is born, but contradicted that by stating that "once embryos were made they should be used for research purposes so they aren't wasted". These two ideas do not align because following fertilization, embryos (either "naturally made" or made by scientists in a laboratory) could potentially be used in a process such as cloning in which a new organism is "born" or given life.

Many times during the interviews, students blurred the line between scientific knowledge and ethical beliefs. For example, when probing students' understanding of "lab-created" versus "naturally-made embryos" and which would be better for stem cell researchers to use, it was discovered that students demonstrate a lack of understanding about the creation and development of the "naturally-made" embryo. As a result, they had difficulty describing how embryos that are created in the laboratory would be different or similar. When students were questioned further in this study about this topic, they often presented ethical ideas/opinions rather than scientific ideas about whether it would be better to create embryos one way or the other, and which would be better to use them for research. Several students suggested that "naturally-made" embryos are unable to give their consent and that their parents do not or should not have the right to do so either; therefore, it would be better to “make” embryos in a laboratory specifically for research purposes. On the surface, it initially appeared that the students understood at least a little bit about embryonic development, but when explored in more depth the fact was that they don’t really understand embryonic development at all, and as a result they do not understand embryonic stem cells; where they come from, how they are used, and the fact that the resulting embryo (regardless of the method of creation) is ultimately destroyed with the removal of cells from the blastula.

As demonstrated in this study, when a student is unaware that their knowledge of a topic is lacking, for example that of embryological development, they have a difficult time connecting that knowledge to something new such as the creation of an embryo in the laboratory or embryonic stem cell research. An instructor should be aware that sometimes lack of knowledge or incorrect understandings can be uncovered by recognizing a student’s inconsistencies between what she knows scientifically and her ethical statements. For example, when students are able to correctly differentiate between adult and embryonic stem cells, yet later state that governmental regulations for both types of stem cells should be identical because “both are similar and used for similar purposes”, then this inconsistency can signal an instructor that the student’s scientific knowledge is likely only a regurgitation of facts.

Only one student accurately described the process of cloning, while none were able to relate cloning to stem cell concepts. Some students were able to describe cloning as a process in which “an exact replica of an organism” was made; however, they later made contradictory statements when discussing ethical considerations of cloning. The following are some of the ethical statements offered: “If God made us and he wanted two of us, he would have made twins", "human cloning could result in chaos, because of the way other people view it", and "it [cloning] gets rid of individualism and there is no purpose to it". A number of students stated that they thought cloning would be acceptable if conducted in a controlled situation with animals in order to help humans. From their responses it was apparent that some of the students thought that if we are able to clone animals and use them to cure human diseases, make new human organs, and such, then in these cases cloning was totally acceptable. In this case, students are not making connections between a variety of biological concepts that would suggest using animals to clone human tissues and organs may not be feasible (i.e., species concept, blood typing, tissue typing…).

Instructional Implications

The fact that high school students hold naïve and alternative conceptions about stem cells should be expected since students have their own ideas and understandings of how many things in the world work, including some scientific and unscientific knowledge of cells. This research study supports the existing research that argues that it isn't easy to help students develop scientific conceptions through traditional teaching methods (i.e., lecture, cookbook labs…) (Smith et al., 1993). For example, in this study all of the students (37) received instruction on cells and cellular organelles, as well as cell structure and function in their high school biology course prior to the interviews. As mentioned earlier, all of the interviewed students were able to correctly draw and label the animal cell, as well as identify key organelles and describe their functions. However, when subsequently questioned about cell division, several students (24% of all students) indicated that cells are all the same and divide the same way. These students did not mention that there are a variety of different types of cells and those cells may divide, for example, via meiosis, mitosis, or binary fission. Knowing that students hold strongly onto the idea that there are only two types of cells (animals and plants) and that these cells divide in the same way —mitosis was the division process usually indicated if any was mentioned— can inform instructional processes. It seems that these early teachings regarding plant and animal cells —possibly dating back to 7th grade life science course work or earlier— persist despite instruction to the contrary that emphasizes that there are many different types of cells and a variety of methods in which individual cells divide. It may also be that teachers hold this alternative conception and have inadvertently passed them on to their students.

High school students are often unaware that their knowledge is incorrect or incomplete, which makes it all the more difficult to bring about a conceptual change in their thinking (Smith, et al., 1993). The instructor's recognition of common naïve or alternative conceptions that students have may assist them in determining where to initiate their instruction and to consider what the most important concepts are that they want the student to learn. In fact, from a constructivist perspective, rather than viewing naïve or alternative conceptions as incorrect, these conceptions could instead be viewed as a foundation for building more accurate and deeper understandings (Julyan & Duckworth, 2005).

Limitations and Suggestions for Future Research

Participants were unfamiliar with interviewing techniques and some appeared to be uncomfortable or nervous with the taping and videotaping of the interviews. It may be that for some questions, despite 8% or more of the participants expressing the same idea, their ideas were not actually alternative conceptions. Instead, it may be that some of the questions were too advanced and the students didn't know the answers. Nonetheless, some of the students were able to make some kind of logical "guess" based on previous understandings of cellular biology suggesting that maybe they also have some misunderstandings about lower-level cellular biology concepts. Unfortunately, this was not probed in this study and may be something to address or at least consider in a future study.

Traditional instruction does not seem to improve students understanding of cellular processes or stem cells as this and other studies reveal. Other studies might include investigating alternative teaching methods which are effective at changing concepts that students have incorrectly obtained and retained regarding cellular biology, and in particular relating that to stem cells. This might include investigating the effectiveness of computer-aided educational materials, models, role play, cartoon concepts and other graphical tools.

In summary, naïve and alternative concepts held by high school students should be of interest to science educators because stem cell research continues to evolve at a dynamic pace and our high school students will soon be faced with making choices regarding the future of stem cells and stem cell research. Stem cell research is a very controversial topic opposed by individuals and groups who often circulate naïve and/or alternative conceptions about the work and ethics of stem cell research. Unless people are educated about stem cells and the related topics, they may not recognize the difference between scientific factual information and that based on ethical or other beliefs, which may further hinder the advancement of stem cell research and the hope and possibility of treatments for debilitating diseases and injuries.

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Appendices

Appendix A: Point Loma Nazarene University's Institutional Review Board's guidelines

Point Loma Nazarene University
Assent To Be A Research Subject

Project Title: *The Identification of Alternative Conceptions Held by High School Students Regarding Stem Cells and Stem Cell Research.*

A. What is this study about?

I (Mrs. Julie Gallagher) am a biology graduate student at Point Loma Nazarene University. I am interested in identifying the alternative conceptions that high school students hold regarding stem cells and stem cell research. Specifically I am attempting to answer the question, "What are the alternative conceptions and justification of those conceptions held by high school students regarding stem cells and stem cell research?" Because you are a teenager in high school, you are being asked to participate in this study.

B. What will happen to me if I am in this study?

1. First, I will give you two copies of different forms to have your parent/guardian read, sign, and return if you are allowed to participate. Then, I will read this form to you. Please follow along with me, because I want to make sure you sign this paper only if you know what you are signing. Then, I will ask if you want to volunteer to be a part of this study. If so, I will ask you to sign this paper and to keep a second copy. When you and your parent/guardian have given permission, you will volunteer for an interview time with me.
2. At an interview time that is convenient for you, you will participate in a one-on-one, audio-taped, video-taped interview with me, Mrs. Gallagher. The interview will have 3 parts, each lasting between 10 and 20 minutes long. Your name will never be used in the report that I will write, and I am the only one who will know your specific responses. Also, your responses will have no effect at all on your class grades.

C. What will it feel like?

Usually kids like to give their opinion on what they think about things. In this interview, you will share your knowledge of stem cells and stem cell research. You will provide your answers while being as honest as possible about what you know. It is possible that you may feel some discomfort or unease if you do not know an answer to some questions, but this is not any different than the experience in a typical classroom.

D. Do I get anything?

Yes, an opportunity to gain additional scientific knowledge about stem cells; following the completion of the interview and interview tasks.

E. What if I have questions?

You can ask me questions at any time. If after the interview, if you have any more questions or want a summary of the results, you can call or email me and ask questions any time at juliemilesgallag5533@pointloma.edu.

F. What are my choices?

You have three choices:

- You can be a part of this project if you want to – sign below.

- You can choose to not be involved in this project. If you decide to not participate, that is OK. Nobody will get mad at you if you don't want to do this, and it will not affect your grades in any way.
- If you decide to be a part of this project and you change your mind later, that is OK too. You just have to tell one of the people in charge of the study – sign below.

_________________________________ _________________________

Signature of student **Date**

____

Name of student (printed)

_________________________________ _________________________

Name of principal investigator **Date**

Please keep one copy of this letter and return the other copy to Mrs. Gallagher

Appendix B: Point Loma Nazarene University
Parental Permission Form to Participate in Research

Project Title: The Identification of Alternative Conceptions held by High School Students Regarding Stem Cells and Stem Cell Research.

Introduction: I understand that my child is being invited to participate in a research study that will take place at Serrano High School. Mrs. Julie Gallagher, a teacher at Serrano, is conducting this study as part of her graduate program at Point Loma Nazarene University. The purpose of this research is to identify alternative conceptions held by high school students regarding stem cells and stem cell research. Specifically she is attempting to answer the questions, “What are the alternative conceptions and justification of those conceptions held by high school students regarding stem cells and stem cell research?” My child’s participation is voluntary and she/he has the option to sign or not sign the assent form, even if I sign the consent form. My child also has the option to withdraw from the study at any time without penalty. Participation or withdraw from this study will have no effect on a student’s overall grade.

Procedures*:* I understand that my child’s participation in this study will take place after school in room 216 at Serrano, and will involve a one-on-one interview session that will last approximately 60 minutes. The interview will be audio-taped and video-taped so that Mrs. Gallagher will have a record of her students’ answers. The door will be open the entire interview and other science teachers will be present next door during interviews.

Risks*:* There is minimal risk involved during this research project, as a result of slight embarrassment over not knowing some answers to the questions.

Benefits: Upon completion of this study, my child understands that she/he may have a greater sense of knowledge of biology. He/she may also understand that she/he may have helped to contribute to the further understanding how to teach biology effectively.

Participation: I or my child may stop his/her participation in the study at any time, which means that his/her individual results will not be included in the data analysis.

Confidentiality: I understand that my child’s records will be held confidential to the extent permitted by law and that my child will never be identified in any publication. Furthermore, I understand that a random participation number rather than my child’s name will be used in data analysis. I understand that my child’s participation is voluntary and that I may refuse or withdraw my child from the study at any time. In addition, my child may also make the decision to withdraw from the study at any time. Only signatures on the consent and assent forms are required for proof of consent and they will be kept separate from the other materials to maintain confidentiality.

Debriefing*:* I understand that I have the right to have all questions about the study answered in sufficient detail for me to clearly understand the level of my child's participation as well as the significance of the research. I understand that I may contact Julie Gallagher (juliemilesgallag5533@pointloma.edu, 760-868-3222) and/or Dr. April Maskiewicz, the supervising professor (aprilmaskiewicz@pointloma.edu, 619-849-2328). I understand that at the completion of this study, I will have an opportunity to ask and have answered all questions pertaining to child's involvement in this study, although I will not have access to my child's specific responses.

____________________________ __________

Signature of Parent/Guardian **Date**

____________________________ _________________________

Printed name of Parent/Guardian **Printed name of student**

____________________________ __________

Signature of Principal Investigator **Date**

Please keep one copy of this letter and return the other copy to Mrs. Gallagher.

Appendix C: Interview Questions

1. How would you describe a cell?
    a. Can you draw me a cell with appropriate organelles?
2. The body is made of trillions of cells.
    a. Are all the cells pretty much the same, or do cells differ?
    b. What are some of the characteristics that distinguish one cell type from another?
    c. Do all cells divide in the same manner? If not, how do they differ?
3. What does it mean when we say "a cell differentiates?" What and how do cells differentiate?
4. What is an embryo? How is it related to a zygote? To a fetus?
    a. What is the time frame between all three of these stages?
5. What do you know about stem cells?
6. Have you ever heard of embryonic stem cells?
    a. What have you heard or what do you know about them?
7. Have you ever heard of adult stem cells?
    a. What have you heard or what do you know about them?
    b. Where can you find adult stem cells?
8. Do you know how embryonic stem cells differ from adult stem cells?
    a. Where can you find embryonic stem cells?
9. Do you know what happens at an IVF clinic?
    a. Do you know what happens to embryos following IVF after couples no longer need or want remaining embryos?
10. Have you heard of the sheep "Dolly"?
    a. Do you know how Dolly was created?
    b. Do you have any idea why the creation of Dolly was so significant to the field of genetic engineering?
11. Do you know what cloning is?

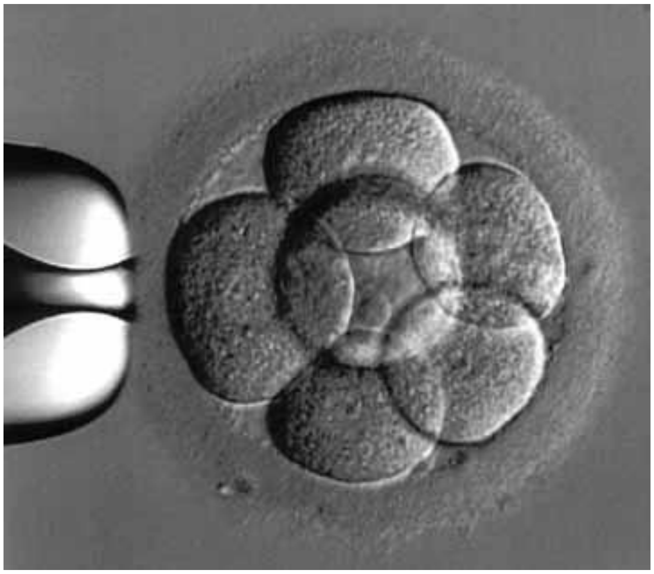
Appendix D: Interview Task

Embryo Card Sort

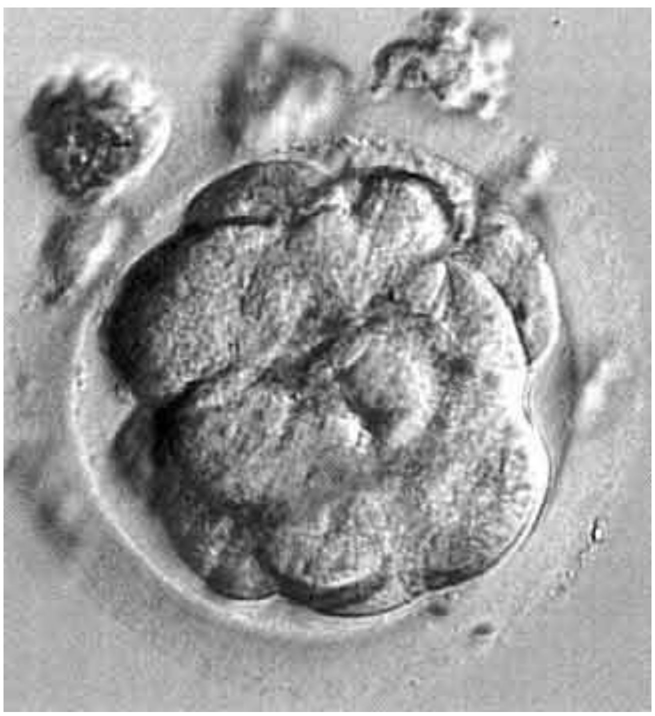
1. Have participant put in order of development
2. Have them point out which one they think represents an embryo

Oocyte. Fertilized egg. (www.advancedfertility.com)

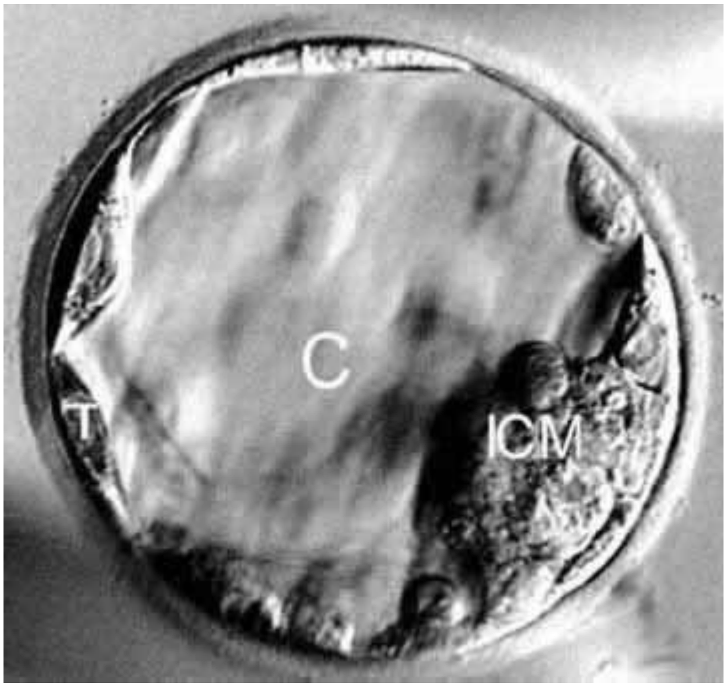
Day 2 after fertilization



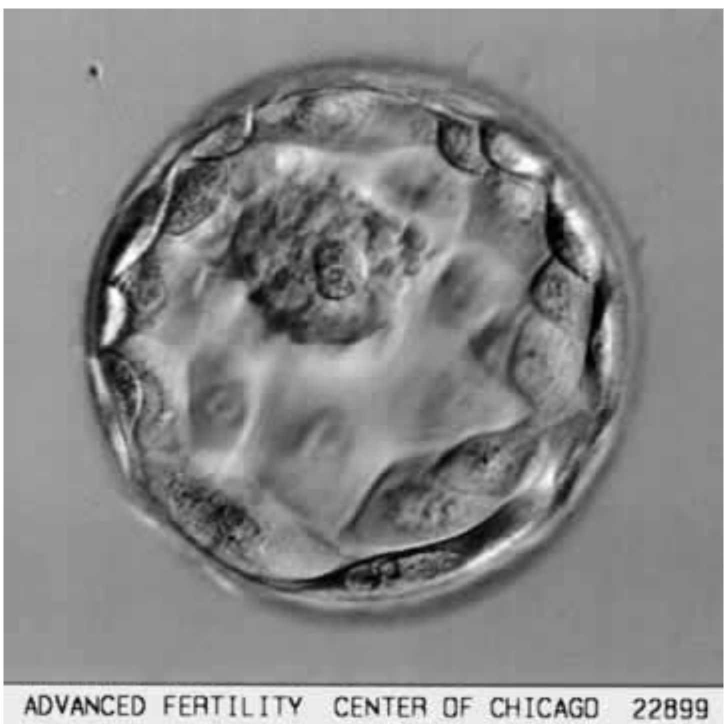
Day 3/8-cell Stage (only 6 cells seen in this plane)



Day 4/ Morula



Blastocyst with Inner Cellular Mass



Blastocyst/Day 5

9 week. Photograph by Ed Uthman, MD. Placed in the public domain and originally posted to the Web on 12 Oct 2001

Appendix E: Scientifically Accepted Concepts and Students' Alternative Conceptions Regarding Stem Cells/ Thematic Analysis Results

Theme	Scientific Concept	Naïve and Alternative Conceptions Obtained from Interviews
Distinguishing Cell Characteristics	The cell is the basic unit of life. A group of cells working together will form tissues. There are two kinds of cells recognized in all living organisms: prokaryotic and eukaryotic. The basic structure of all cells, whether prokaryotic or eukaryotic, is the same. However, function will vary. Some organisms are unicellular. Other organisms are multicellular and are made up of a number of different cells with different functions (e.g., sperm cells, egg cells, nerve cells, bone cells)	• The cell is a microscopic thing that makes up an organism. • The cell is the smallest living component of an organism. • Cells all divide the same way. • All cells are pretty much the same and do the same thing. • Cells do not divide differently; they instead divide at different speeds depending upon where they are. • Cells divide differently based upon their shape.
Differentiation	Process of a cell becoming more specialized. Groups of specialized cells may form tissues in the multicellular organism.	• One cell may change/mature into whatever tissue it must form. Organelles that are needed grow or develop more or unnecessary cells shrink.

	Changes are due to gene expression. These changes may change a cell's size, shape and function. Adult and embryonic stem cells both change into other cell types. Adult stem cells differentiate to repair tissue and replace worn out cells. Embryonic cells may be pluripotent, totipotent, or multipotent.	
"What is an embryo?"	Stage beginning with first mitotic divisions of zygote. Developing organism from conception to implantation (first seven or eight weeks). Includes blastula, gastrula, and organogenesis stages of embryonic development.	• An embryo is an immature egg. • The start of a baby before the sperm connects with it. • An underdeveloped animal. • It is a developing zygote/it's a zygote. • I heard of it mostly in reproductive terms that an embryo is what is in the female when the sperm goes into the female and fertilizes the egg.
Stages of embryological development	Fertilization leads to a zygote. The zygote then begins cellular division: Day 1: first cleavage (two cells). Day 2: second cleavage (four cells). Day 3: 6-12 cells (can test for genetic diseases if IVF is done). Blastocyst	• A zygote is before the egg is fertilized. • An embryo forms a zygote, then a fetus. • The embryo is when you can start seeing the baby on an ultrasound. • 1-4 weeks for the zygote. • 4-9 weeks for the embryo.

	Day 4: morula. A solid ball of 16-32 cells. Day 5: solid morula becomes a hollow, fluid-filled blastula. ICM forms the embryo. Implantation in uterine wall. Day 6-7: blastocyst attaches to endometrium. Day 7-10: gastrulation (formation of germ layers). Embryo (week 3-8). Fetus (week 9 till birth).	
Embryonic stem cells	Unspecialized cells found in the inner cellular mass of a blastocyst at 4-6 days post- fertilization. Usually derived from embryos that have been fertilized *in vitro* and donated for research. Embryonic stem cells have the potential to differentiate into any of the 200 various kinds of cells known in the body (Pluripotent).	• Found in the embryo. • Develop in the nervous system in the baby, in the womb. • Found in the umbilical cord and in the fluid within the umbilical cord, which could be saved since it is full of embryonic stem cells. • Not found in the bone; they were in the brain stem.
Embryonic stem cells and their location	Embryonic stem cells are isolated from the inner cellular mass of a blastocyst; approximately 4-6 days following fertilization. Blastocysts are created from a fertilized egg/zygote or from therapeutic stem cell cloning.	• Come from umbilical cords and can later be used for stem cell transplants to cure cancers such as leukemia (or they are the first cells forming zygotes). • They come from potential babies. • They come from the umbilical cord of an embryo; either an aborted one or after it is

		born. The fluid containing the stem cells is saved. • They are cells developing in the nervous system in the baby in the womb. • They come from aborted babies. • In the back of the brain. • In the ovaries. • In umbilical cords. • All over the body. • The embryos' brain stem or bone marrow.
Adult stem cells	Undifferentiated cell that can be found among other differentiated cells and is able to renew itself and differentiate to become a specialized cell making up a tissue or organ.	• They are mature cells that can serve to become different types of cells. • They can function as any type of cells. • They are older in age?
Adult stem cells and their location	Adult stem cells, previously thought to be difficult to find, have been found in almost every tissue in the human body. They undergo mitotic division to replace damaged or dead cells.	• In a developed embryo. • In adults. • In the spinal cord.
Differences between embryonic and adult stem cells	Differ in the number and type of differentiated cells they can become. a) Embryonic stem cells are referred to as being pluripotent due to the fact they have the ability to differentiate into all the	• Maybe the time they take to become stem cells? • Just age, I guess? • Embryonic cells are immature, while adult cells have fully developed. • One is for animals and one is for humans. • Adult stem cells are able

	body cell types. b) Adult stem cells are limited to differentiating into the cell types they originated from. c) Embryonic stem cells can be grown in the laboratory in culture. d) Adult stem cells were previously thought to be difficult to locate in mature human tissues and difficult to culture. During the last twelve months scientists have disproven this. Adult stem cells have been used for decades in bone marrow transplants. e) Embryonic stem cells maybe too unspecialized to control without some modification. (Fetal cells have been transplanted, but have shown they may possibly give rise to cancer).	to differentiate into different types of cells. • Embryonic stem cells could help to replace organs. • One comes from babies, while the other comes from adults.
In Vitro fertilization	In vitro fertilization is a procedure utilized in fertility clinics that enable infertile couples to have eggs removed from a female's body and subsequently be fertilized in a glass dish in the laboratory. A few of the healthy embryos are	• Mature ova are cultured and developed into embryos. • Sperm is donated and it depends on whether there is an embryo or not. Sperm is injected into the embryo to get the fertilized egg. For example in the Octomom case, the doctor put too many in

	implanted in the female's uterus.	and there were too many embryos. • They take stem cells from the embryo? • They fertilize a moms' egg with the preferred new stem cells. • They give the woman a drug so she becomes more fertile, then they inject eggs into her.
IVF and the Fate of Excess Embryos.	Excess embryos are deep frozen in liquid nitrogen (cryopreservation). Excess embryo's may: -lose viability during freezing process, thawing procedure, some kind of malfunction or operator error. –be used in second attempt to conceive. –be donated to couples unrelated and unable to conceive ("snowflake babies"). Excess embryos that are not preserved, are often flushed down sink drain while alive, or are discarded, destroyed, incinerated, exposed to dry air, donated to research and experimentation, training, diagnostic purposes, etcetera. Approximately 8% (11,000) of all embryos are actually used in research; the rest are	• Abortion.

	destroyed.	
Cloning	Nucleus of unfertilized ova is removed and replaced by the nucleus of a body cell from an existing organism. The ovum is induced to grow and develop into an embryo. Reproductive cloning: clone is implanted into female uterus and carried to term. Therapeutic cloning: cells from the inner cellular mass will be removed in days 5-7 and the embryo will be destroyed in the process.	• Cloning is extracting DNA, replicating it, inserting into an egg and letting it develop. • Growing an embryo from stem cells and then implanting them into a female organism. • It is when a somatic cell is added from a cell is added from a donor and the cell grows to produce embryo and makes a clone. • Making copies of babies. • It is when a human is made from the cells of another. • Where they make the exact opposite of something.