Science Education through Stories: Collection of stories on a website

A portfolio submitted in partial fulfillment of the requirements for the degree of

Master of Education

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Abstract

Stories are a traditional means of communication that play a role in transferring values belonging to culture from one generation to another and also acts as a powerful pedagogical tool helping people to process their daily experiences. Stories can be a dynamic educational tool that provides instructional flexibility. Moreover, it can be used in the science classroom by incorporating scientific facts and the nature of science into fiction to teach science and how to do science. Narratives can be used in the science classroom not only to develop the cognitive domain but also the affective domain and soft skills in students. This portfolio is a collection of stories written along with connections to the Ontario Science Curriculum and additional resource material in the form of a website focused on changing stereotypes through biographies and teaching concepts through content-based stories.

Acknowledgement

The completion of this undertaking could not have been possible without the motivation and guidance of my supervisor, Dr. Joan Chambers.

With all regards, a heartfelt thanks to Dr. Joan Chambers and Dr Thomas Puk.

I would like to express my gratitude to all the people who helped me to finish this task.

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Chapter 1: Introduction

We frequently come across stories during our daily lives, sometimes entertaining us or teaching us a lesson. One such story I remember is from the microbiology class at Panjab University. Our professor asked us an unexpected question: What is the Archimedes Principle? I was surprised not only by the question but by the fact that no one from the class was able to answer it, though it is one of the basic principles taught at the intermediate level in school. When students were not able to recall, the professor was surprised. He first asked us if we had heard about the Archimedes bath story and told us that their teacher in school used the story to teach them about the principle. This story (Archimedes bath story) taught me the law, but more importantly, a different and memorable way to teach scientific theories and principles. Building on this experience and research done in the field, I highlight the use of stories to teach science, especially, how to *do* science or to address social issues present in science education. Hasper (2019) opens the blog 'The Art of Story-telling with Anna Hasper' with the lines "storytelling is one of the oldest and most powerful ways of sharing ideas and transferring knowledge from one generation to the next. It [also] brings people together as they sit and listen to the storyteller, hanging on their every word and enjoying the events as they unfold." Kromka and Goodboy (2019) further suggest that student learning done using storytelling is more retrievable and memorable as compared to learning through lectures because students remembered the facts from the stories. Thanks to stories, it is possible to present an opinion or to give a message more quickly and effectively. Stories are also a traditional means of communication that play a role in transferring values belonging to a culture from one generation to another (Laçin-Şimşek, 2019).

By using stories in the classroom, we as teachers can connect to more students and address students who are often left behind (like attention deficient students, students not affected by facts, students connecting with emotions). It is a medium that can engage a diverse group of students. I believe that stories in science classrooms can capture creative and thoughtful students' attention and make scientific concepts available to them in a way that their brains can process, particularly with a class of individuals with different processing mechanisms.

I created a website for Grade 10 science courses (Academic and Applied) in The Ontario Science curriculum (OME, 2008), which contains a variety of stories including: biographies of scientists to break stereotypes and content-based stories as a 'hook' in the classroom. The stories are accompanied with the curriculum links, notes for the teacher, discussion questions, and additional reference material. This portfolio includes a review of the literature focused on the use of stories in education, specifically in the science classroom, and how to create useful stories. Based on the review, the chapter following contains the information about the stories and their curricular connections. Finally, I include an introduction to the stories, followed by the stories.

Chapter 2: Literature Review

Stories in Education

Narratives or storytelling is a way to pass knowledge from one generation to the next generation (Morelli, 2017). As Kromka and Goodboy (2019) argue, "If storytelling is an art developed during the beginning of human history, probably to teach the wisdom of generations past, then storytelling is, by definition, a pedagogical tool, helping people to process their daily experiences" (p.22). Story is defined as a discourse element (symbolic actions in the form of words or deeds in a sequence and conveying meaning for those who created or interpreted them), designed individually to describe a significant event (Fischer, 2019; Kromka & Goodboy, 2019). Narratives encourage students to revise their ideas and understanding of the lesson, leading to acquisition and retention of information. It also appeals to emotion and building emotional connections; thus, narratives can be used to influence the effect and have a role in nurturing student attention.

Kromka and Goodboy (2019) highlighted the above outcomes of using storytelling in the classroom and implied that to maximize the potential of these benefits instructors should use good stories. A narrative is used effectively by orienting the students to the relevance of the narrative; making a clear start, body, and end; emphasizing the evaluation of the content by the students; building connections and finding the missing links; using a positive emotional tone; and lastly, making sure the students perceive the context correctly. Further, Kromka and Goodboy (2019) also suggested to use narratives frequently in class to break the monotony. The use of stories does not undermine the importance of facts but suggest that facts and fiction can go hand in hand.

Importance of Inquiry and Facts

Donna Haraway (2016), in her book *Staying with the Trouble*, talked about using stories and science fiction as a medium to build connections between humans and Earth. However, Haraway argues that though some stories may be more evocative than others, it does not mean that they are suitable. Greenhalgh-Spencer (2019) argues in a similar vein: he suggests blurring the lines between fact and fiction may have a negative impact, and refers to Haraway's and his own stories. Though he believes that context matters, sometimes understanding of context is based on the reader's interpretation. Greenhalgh-Spencer argues that stories should be telling the truth and focus on presenting scientific facts or actual experiences.

Greenhalgh-Spencer's (2019) argument further informs the research method of narrative inquiry. Narrative inquiry is a qualitative research method that identifies real experiences and relates them to experiences or lessons in story format, which can have a significant impact. Greenhalgh-Spencer concludes that different types of accounts should be used in curricula and further suggests developing a pedagogical practice (similar to nursing education: critical narrative pedagogy), that is, using the power of storytelling to develop an analytical frame of mind within learners.

Fischer (2019) found that problem-solving and teamwork skills can be developed by using fictional stories. Such stories promote deep learning and further enable discussion on sensitive topics. Fictional stories can help to build a community of learners, and these stories can be altered according to learning objectives. They can be easily modified to enable instructional flexibility (Akuma & Callaghan, 2019). Educators can certainly be creative while using a fictional story; such stories can be a dynamic educational tool and full of life (Langfield, 2016). The use of fictional stories provides greater instructional flexibility than factual narratives, and

educators can modify the story in countless ways to target students' interest and queries, making a problem-based learning exercise more interesting (McDrury & Alterio, 2016). Be it based on facts or fiction; stories can be employed by educators to not only teach about social issues but also science.

Science Education

An article "Climate Science Meets a Stubborn Obstacle: Students" in The New York Times in June 2017, reported a case where the teacher, James Shutter's, effort to inform students about the effects of climate change and global warming failed as the students refused to accept the facts. The students were not interested in the "facts" because of the culture and anecdotal stories (incidents from friends and family) prevalent in their community (Harmon, 2017). The students were questioning the validity and reliability of scientific data and James Shutter's position on climate change as undependable.

Hilton (2019), also talks about the disbelief in science and highlights that facts no longer speak for themselves. He acknowledges a shift away from belief in "facts" due to the pedagogy of knowledge transmission whereby knowledge (facts) presented by a teacher is intended to be used by the students to understand the functioning of the world. However, students often no longer view the teacher as an "expert" and do not believe the information they are taught. Hilton (2019) highlights a critical need to address the issue (belief in anecdotal evidence over factual or empirical evidence) to develop responsible citizens.

Adding on, Garcia-Carmona and Acevedo-Diaz (2018) suggest that understanding the nature of science (NOS) is an essential part of a citizen's scientific literacy. The argument is about the focus on teaching students about science rather than teaching them "how to do science" (Matthews, 2009). The understanding of NOS will help people evaluate "public issues related to

science and technology" (p. 436) and further help their understanding and be critical, constructive, and accountable citizens (Garcia-Carmona & Acevedo-Diaz, 2018). Providing the student with meta-knowledge about scientists' work and working as a scientist in the classroom helps to improve students' understanding of NOS. Moreover, it helps to address the concerns: "It is like you cannot disagree with a scientist or you are 'denying science," and the disbelief of students, highlighted in The New York Times (2017) newspaper article.

Science is not about remembering and believing in facts, rather it is about finding answers to the unknown (Matthews, 2009). Using this practice, teachers can bring the focus back from the use of anecdotal evidence and personal belief to evidence-based arguments about controversial issues (Hilton, 2019). Hilton identifies the need to address the way students think and formulate their opinion. As opinion is formed by society through dialogue, he suggests the use of stories and narratives over just facts to help shape belief. Also, as was the case in James Shutter's science class, when students found and identified the descriptions from the community coinciding with their teacher (through field trips to nearby woods and a local stream), they identified the effects of climate change, and one of them said: "This is happening, and we have to fix it," (The New York Times, 2017).

Facts come from scientific study and opinions come from peoples' narratives (not dependent on logic). These two can be used together: facts can be used to inform stories and to shape an opinion which has a basis in logic (Hilton, 2019). Several researchers have completed studies based on these premises and came up with the conclusion that stories can be used in science classrooms. Stories can be used for different reasons such as: an instructional strategy (Walan, 2019), to increase student recall and attention (Kromka & Goodboy, 2019), to develop

interest (Klassen & Klassen, 2014), and to change stereotypes (Horton, 2013; Leblebicioglu, et al, 2011).

Stories in science classrooms can be used to teach science and how to do science, but they are not limited to the development of cognitive abilities (Banister & Ryan, 2001; Fischer, 2019; Kromka & Goodboy, 2019). Narratives can be used in the science classroom to develop the affective domain and soft skills in students such as teamwork, organization, values, and build community (Kromka & Goodboy, 2019; McAdams, 2019).

The next concern is where to find such stories, as available resources are limited. Even literature does not have much to say; it is limited to the use of stories, their pros and cons. It lacks information on the source of stories that can be used in classrooms, whereas there are suggestions on sharing a narrative based on experience (Kromka & Goodboy, 2019) and about the history of science (Fischer, 2019). On the other hand, there are websites sharing biographies of scientists, long stories or even children's storybooks linked to science which serve as a collection or a reservoir of stories (example; https://www.biography.com/, https://www.storybehindthescience.org/, https://www.stem.org.uk/teaching-science-through-stories) but lack specific connections to the curriculum, specifically the Ontario secondary science curriculum.

To sum up, stories can catch students' attention (a natural hook for students), give students a mental organizer, and help students change/switch gears. Storytelling is an effective way to teach lessons, a gentle and effective way to pass on concepts and values, which helps to build bridges between people and the natural world, and above all, it is fun for students and teachers.

Creating Stories for the Science Classroom

The arguments above show that creating an account for a science classroom is not an easy task. When creating a story great care and precision is needed, targeting the element of inquiry. It is also important to understand the types/nature of stories that can be used in a classroom and the message that needs to be conveyed. Kevin Strauss (2006), in his book *Teaching Science through Stories*, suggests that "Fable or Anecdote," "Folktale," "Why or Pourquoi Stories," "Personal Stories," and "Histories" are the types that can be used in science classrooms to teach science.

History of Science. The use of stories involving historical narrations is becoming popular, and it is believed that historical accounts can act as a vital resource in the teaching of science (Laçin-Şimşek, 2019). Science history, when used appropriately, can help students realize the historical developmental phases of the subject/matter they are learning. Thus, stories are essential tools that help students appreciate that new scientific knowledge is a result of human endeavour (short-term or long-term work), and makes students aware of the disappointments, pauses, and successes in the endeavouring process (Laçin-Şimşek, 2019). Therefore, the stories would humanize science (not only a body of facts but also its processes) and thus help them learn about the nature of science (Pellegrino, Peters-Burton, & Gallagher, 2018) and the content (Isabelle, 2017).

A history of science provides opportunities for students to appreciate that scientific and mathematical progress does not amount to a series of discoveries, but that the growth is characterized by feats of imagination and creativity (Isabelle, 2017). The history of science is full of accidents and conjunctures and curious juxtapositions of events. The use of historical science, including drawing upon these dramatic episodes, astounding discoveries, and intriguing

characters in history, leads to an exciting storyline. The "Under Pressure Story" of Otto von Guericke's Magdeburg hemisphere, to teach the concepts of air pressure (Isabelle, 2017); the tale of Newton's apple (gravitational forces); and, Archimedes' bath story (Archimedes Principle), are examples of such stories.

Historical Context. Science itself could be considered a series of stories compiled together in a logically progressive way. Before the term "science" came into existence, people were attempting to make sense of the natural world. Stories were created to explain natural disasters, death, disease, and phenomena that seemed too difficult to explain to humankind. Use of "Fable or Anecdote," "Folktale," and "Why or Pourquoi Stories" (mythological stories) are some examples (Strauss, 2006). Today these stories can be used to teach students about evolution, diseases, and epidemics (Horton, 2013). Use of stories like *The Little Elves and the Magic Axe of Espen* can help students to understand the background and importance of invention to people. Further, the use of historical or Indigenous contexts to provide facts, help in retaining the information better, particularly compared to when facts are presented within textbooks. Further examples include, the Greek myth of Persephone kidnapped to the underground kingdom of Hades to teach the cycle of change (Seasons) on Earth, and another mythological story (from Pourquoi stories) of how the opossum came to have a bare tail to teach evolution and adaptations in animals (Strauss, 2006).

Human Face to Authority. Textbooks often provide a simple synopsis of historical events and figures devoid of emotion and life (Finson, Farland-Smith, & Arquette, 2018). On the other hand, children's stories take the time to paint a full picture of the human experience (Dajani, 2017). When we take the time to present scientists as human beings (those people who experience failure as well as success), then our students can begin to relate to these people, and

their stories become personally meaningful (Hilton, 2019; Horton, 2013; Klassen & Klassen, 2014). For example, teachers, when teaching Newton's laws of motion, might be presenting in a PowerPoint presentation, introducing Newton's First Law, providing an example of application, and then progressing to the next one. With this practice teachers sometimes fail to provide the historical context and origin of these laws. Who was Newton? What life experiences led him to become the scholar he was? How did he come up with these laws? However, when students learn a little bit more about Isaac Newton's background, they can see how people who come from the most troubled past can still achieve great things. The use of biography provides a human face to science (Laçin-Şimşek, 2019; Pellegrino, et al., 2018).

Sometimes, students and teachers perceive scientists as omnipotent holders of all the world's knowledge, and geniuses to whom they can never relate. Students must understand that scientists also have flaws (Horton, 2013) and that they are humans. In reality, Isaac Newton had family, friendship, health, academic, and ethical issues, just like many students. Through this understanding, science becomes a discipline for the general public and not only for the elite (Horton, 2013; Prakash, 2019).

Alternative View. Several studies have already investigated children's stereotypical images of scientists as being male, old, bald, wearing eyeglasses, working in laboratories, and so forth (Leblebicioglu, et al., 2011). Most science textbooks represent this view and contain few representations of female and/or minority scientists (Gheith & Aljaberi, 2019). The actual picture of the scientific world is diverse and works in many different environments. By incorporating books and stories about women and minorities in science into their practice, teachers can provide students with a more realistic view of scientists at work (Finson, et al., 2018). For example, the image of scientist portrayed in the children's book *Listening to Crickets: A story About Rachel*

Carson is of a woman who works in the field to collect data (Ransom, 1995), thus targeting the gender stereotypes and work environment stereotypes (Finson, et al., 2018; Garcia-Carmona & Acevedo-Diaz, 2018). Ransoms' (1995) choice to portray Rachel Carson was purposeful and contradicted what some students would classify as doing science. Having a text on hand like *Girls Think of Everything (2018), highlights the innovations by women and girls, and* shows students a bigger picture of the scientific community and its members.

Quality Assurance. Literature suggests the use of stories to improve the learning process but also proposes that stories should be wisely used, taking into account the boundaries of facts and fiction (Greenhalgh-Spencer, 2019). Klassen (2014) argues that there is a lack of literature to test or assess the quality of stories used in the science classroom. So how to decide and work with stories?

Kevin Strauss (2006), suggests "three points in any educational lesson where a teacher could use a story: opening, transitions and closing" (p 5) referring to when to use stories in a classroom, and also gives instructions on how to include stories in the classroom. His criteria of identifying four story scenes and drawing them in four boxes could be used to test the quality of the story, along with the use of a criterion-based narrativity rating schema by Klassen to test the applicability of the story, based on the narrative and other aspects of a science story. The first is the narrative aspect of the story pertaining to "characters", "actions", "situations", "consequential coherence" and "past time". Second is the plot structure categorized into six elements; "setting", "a problematic situation", "a crisis", "a critical decision", "the climax" and "the conclusion or resolution". Other aspects are agency, science, and NOS content (Klassen, 2014).

Conclusion

Narratives or storytelling is a way to pass knowledge from one generation to the next (Morelli, 2017). When used as a pedagogical tool in the classroom, stories help students to: 1) retain information; and 2) appeals to their emotions. Thus, narratives can be used to influence the effect and have a role in nurturing student attention (Pellegrino, et al., 2018; Walan, 2017). Literature also suggests that using the approach of storytelling in the classroom and the selection of good stories is beneficial (Hilton 2019; Pellegrino, et al., 2018; Walan, 2017). It is important to orient the students to the relevance of the narrative (making a clear start, body, and end), emphasizing evaluation by the students, building connections, using a positive emotional tone, and lastly making sure the students' perceptions are realistic and have a basis in logic (Kromka & Goodboy, 2019).

Fictional stories can be employed to develop problem-solving and teamwork skills, thus promoting deep learning and further enabling discussion on sensitive topics (Fischer, 2019). However, Greenhalgh-Spencer (2019) has concerns about blurring the line between facts and fiction, which may have a negative impact. Whether using fictional or factual stories, stories should be crafted with precision depending upon the learning objectives and expected outcomes. Whether based on facts or fiction, stories can be employed by educators to teach not only about social issues but also science.

Science educators need the support of stories to address the students of the post-trust era, where facts do not speak of themselves. Facts need to be backed with emotional connections, using stories to address the disbelief in science (Hilton., 2019). Another reason for the use of stories is to give examples and encourage students to do science rather than just knowledge transmission (Garcia-Carmona & Acevedo-Diaz, 2018). Facts can be used to inform stories

having logical bases (Hilton, 2019), used in science classrooms as an instructional strategy (Walan, 2019), to increase student recall and attention (Kromka & Goodboy, 2019), to develop interest (Klassen & Klassen, 2014), and to change stereotypes (Horton, 2013; Leblebicioglu, et al., 2011).

To sum up, stories can catch students' attention (a natural hook for students), give students a mental organizer, and help students change or switch gears. Storytelling is an effective way to teach lessons, and a gentle and effective way to pass on concepts and values, which helps to build bridges between people and the natural world, plus it is fun!

Stories help students to understand better and retain information, humanize science, help to understand the nature of science (acts of imagination and creativity), and identify scientists as human (experience failure and success). Moreover, stories highlight the importance of the ingenuity of people, encourage students, and also provide an alternative view to the meaning of the word "scientist," thus changing stereotypes.

Chapter 3: Methodology/Plan

The application of this portfolio is to create web-based resource material in the form of a website, which could be used in the science classroom. This website has been created using Google Sites. The material contains stories, curriculum connections (grade level, topics), and suggested instructions on how to use these stories to enhance engagement of students in the science classroom, along with notes for teachers and additional reference information. This work includes eleven stories (written by me) in the form of biographies, short stories, and content-based stories. The stories represent a compilation of information I collected about the scientists and their work and my own creativity.

The Stories

Biographies. Biography or life story is an account of person's life written by someone else, showing their life history or struggle and their personality (Cambridge Dictionary). The biographies of scientists can be used by teachers to encourage students and as a way to hook students' attention, during introductions or transitions in lesson plans. Similarly, short stories can further be used by teachers to normalize the concept of women and girls in science. Both biographies and short stories can be used to break the stereotypes and promote a healthy environment that supports and encourages every student irrespective of gender, community, or ethnicity, showing a realistic image of the science community. Teachers can use these stories in science classrooms which are linked to Section A of the Science courses of Grades 9 and 10 of The Ontario Curriculum (OME, 2008), though the use is not limited to a science classroom or a certain grade level. This work is focused on identifying biographies of scientists who made contributions to the fields of science and contains two biographies plus five short stories of female scientists.

The first story is of A. P. J. Abdul Kalam's life, and his wise words are a source of inspiration for millions. Words from his biography *Wings of Fire*: “The best brains of the nations may be found on the last benches of the classrooms” (Kalam & Tewari, 2015, p. 53), encourages students in the classroom setting. When one looks at his image, though, he fits into the stereotypical image of a scientist (old, male, authoritative, and aloof) (Figure 1). However, his life story is an excellent example of breaking stereotypes, which also is a reason to include his biography on the website. His life teaches us about dedication to goals and hard work, irrespective of the obstacles (they are not the end but a learning opportunity):

> *If you fail, never give up because F.A.I.L. means 'First Attempt in Learning.' End is not the end; in fact, E.N.D. means 'Effort Never Dies.' If you get No as an answer, remember N.O. means 'Next Opportunity', So let's be positive.* Press Trust of India. (2015, July 28)

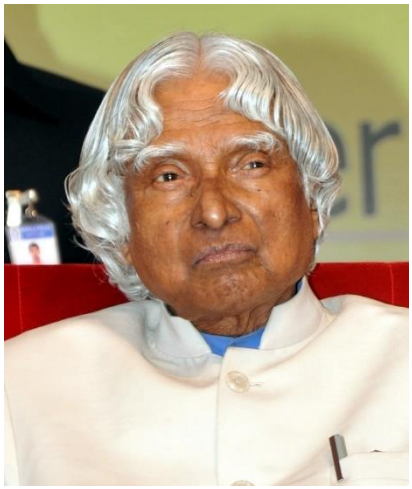

Figure 1: A.P.J. Abdul Kalam (Shanmugam, 2014)

The second biography is of a Nobel Laurette, Dr. Barry J. Marshall, showing his ultimate dedication to research of *H. pylori* (including the incidence of drinking a harmful bacterial culture). Again, the reason to include this story is to make students aware that scientists come from all parts of the world. His story also highlights the prime level of persistence and uprightness, which we should seek to accomplish through our work regardless of the outside circumstances of prejudgment and delusion. Also, uncertain faith in his research and his

experience is represented in a comic *Ulcer Tales* (Facebook post by Nobel Prize, 2019, January 6).

The next piece of work includes five short stories of women and girls in science inspired by the children's books: 1) *Listening to Crickets: A Story About Rachel Carson* by Ransom (1995); 2) *Girls Think of Everything* by Catherine Thimmesh (2018); and, 3) *Women in Science: 50 Fearless Pioneers Who Changed the World* by Rachel Ignotofsky (2018). Stories of women in STEM and creative inventions by women and girls which made life easier, can be used to break the stereotypes and promote a healthy environment in the classroom. The website embraces stories of women who paved the way for others in their field and includes stories about scientists Edith Clarke, Gerty Cori, Jane Cooke Wright, and Esther Lederberg. Hedy Lamarrs' story is an example of an ingenious inventor. (Note: Appendix A contains the Biography Stories in full.)

Content-Based Stories. Next are four content-based stories that can be used to teach some scientific concepts in Section B: Biology of the Grade 10 Science courses (Academic and Applied) of The Ontario Curriculum (OME, 2008). Content-based stories are narratives created using factual information based on logical reasoning, centered on curricular science concepts, and inform the affective domain (Hilton, 2019).

The first story is based on the Ted Talk by Manu Prakash (2019), who is professor of bioengineering at Stanford University; he talks about the Foldscope and Paperfuge. The story is in the form of a fictional diary entry of a student sharing their experience of attending a guest lecture by Manu Prakash and using the foldscope, a small and inexpensive microscope. This story addresses a concern related to public health and disease control, and also of the value and accessibility of modern technology.

The second story is about the famous sheep, Dolly. It discusses clones and how Dolly came into existence, the process of making a clone, the life of the sheep, and the ethical considerations of cloning.

The third story refers to the concept of the cell cycle. It discusses the lifespan of a cell and its growth and division along with the checkpoints or the regulations it faces during different stages of life.

The fourth piece is the story of smallpox, highlighting the history of the worldwide spread of the disease and earlier attempts of controlling its spread. This also includes the Edward Jenner experiments and discovery of vaccination for the disease.

Each story on the website is connected to the curriculum and to the topics (briefly described in textbooks) having an impact on citizen/student actions. It also contains notes for teachers (on how to incorporate them in the classroom), questions for discussion, and additional reference material. (Note: Appendix B contains the Content-based Stories in full.)

Chapter 4: The Website

In this chapter, I include screenshots from the website to illustrate the design of the site and examples of the information contained within. The website contains links to each of the stories located on the applicable main pages (see Figures 2 and 3). Example story pages (see Figures 4 and 5) include links to information for the teachers, such as lesson ideas, activities for students, and additional resources (see Figures 6 and 7).

About [the website]

I am a Masters of Education student at Lakehead University, Thunder Bay, Ontario. Through this portfolio, I created a platform where educators can find stories that can be used in the science classroom. The creation of this website represents a small effort to create resource material for teachers relating stories to science lessons. These stories are presented as biographies in Appendix A and content-based stories in Appendix B, along with the additional resource material provided on the website for the teachers and resources used to create them. Stories can catch students' attention (a natural hook for students), give students a mental organizer, and help students change/switch gears. Moreover, storytelling is an effective way to teach lessons, a gentle and effective way to pass on concepts and values, helps to build bridges between people and the natural world, and above all, it is fun for students and teachers.

Name of website: Stories of Science

Url: https://sites.google.com/lakeheadu.ca/stories-of-science/home

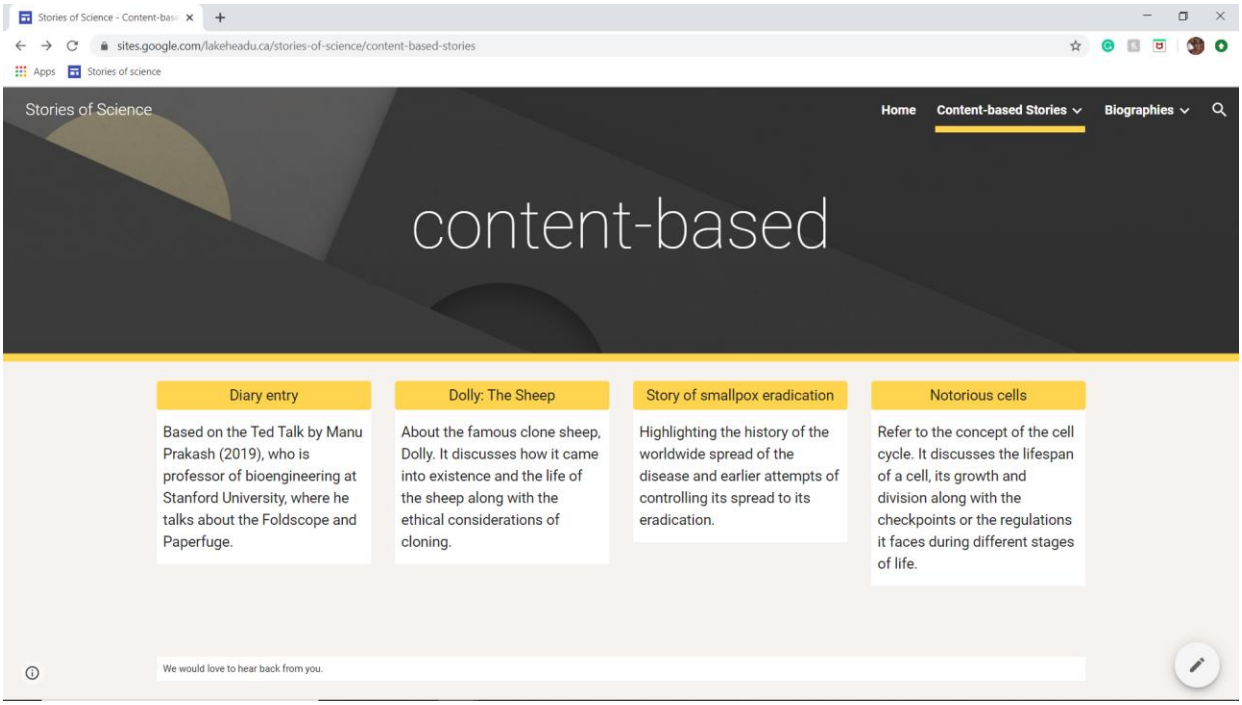

Figure 2: Screenshot from the website page, introduction to the content-based stories.

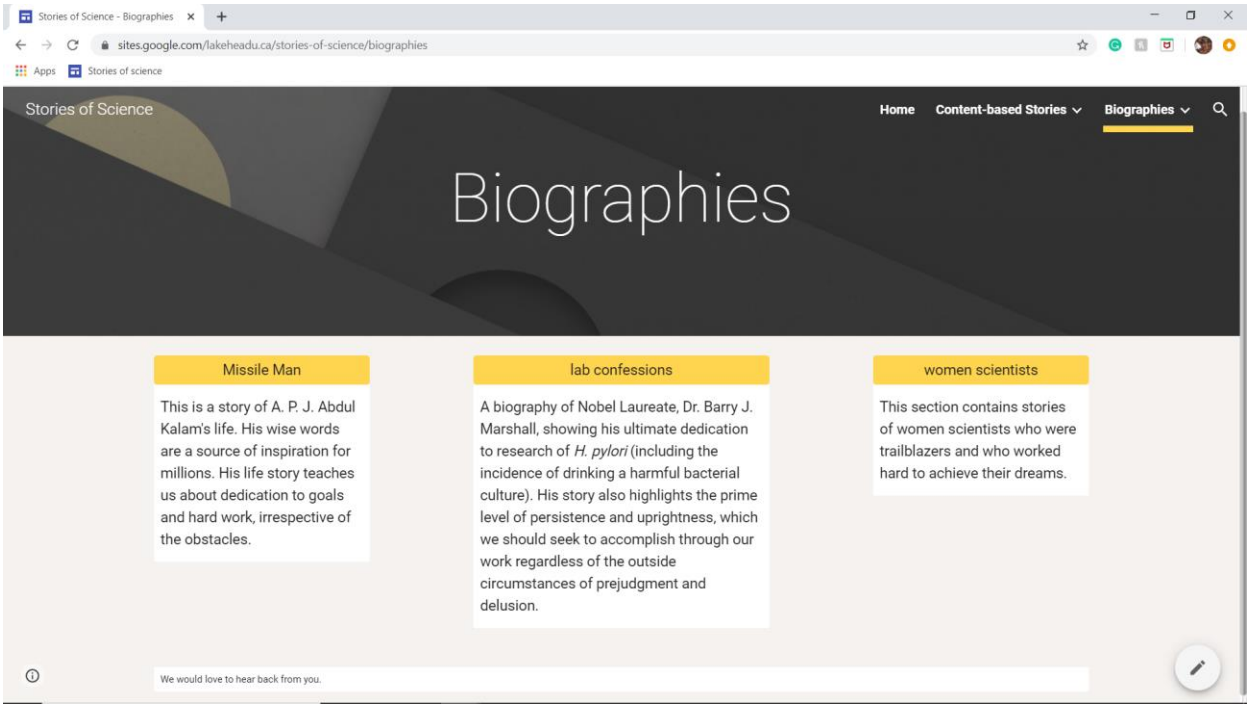

Figure 3: Screenshot from the website page, introduction to the biographies of scientists.

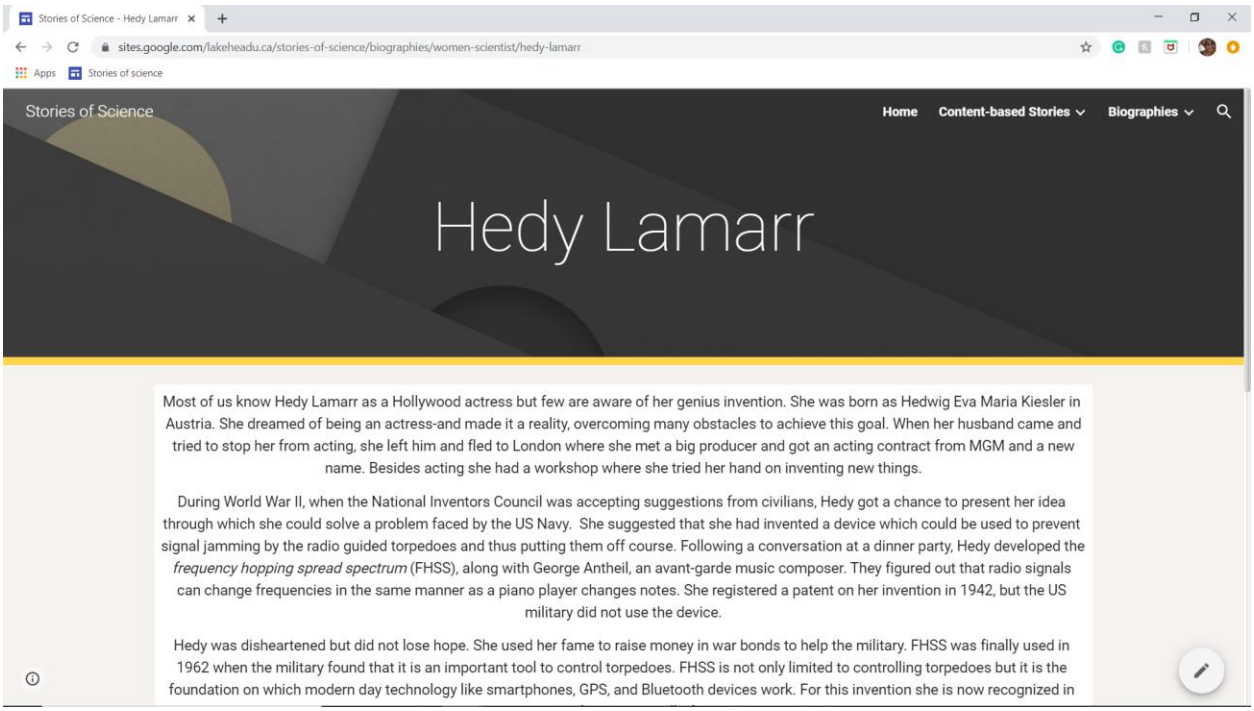

Figure 4: Screenshot of a story page from the website, Hedy Lamarr.

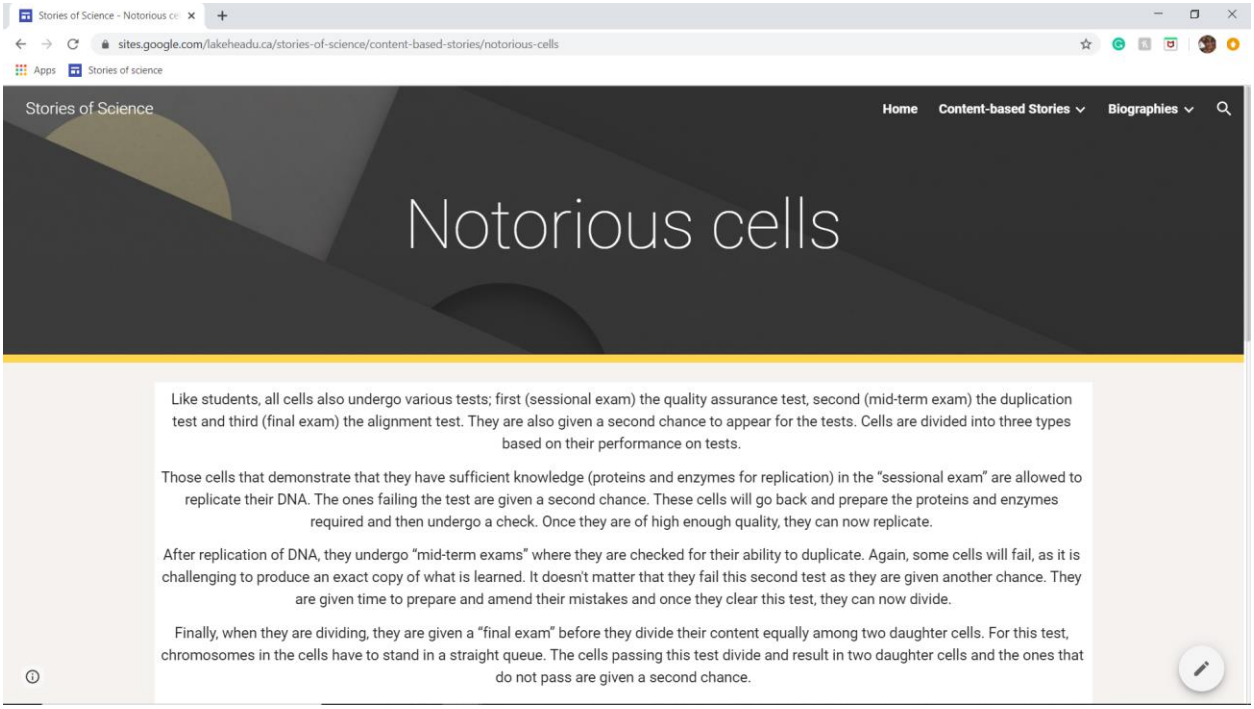

Figure 5: Screenshot of a story page from the website, notorious cells.

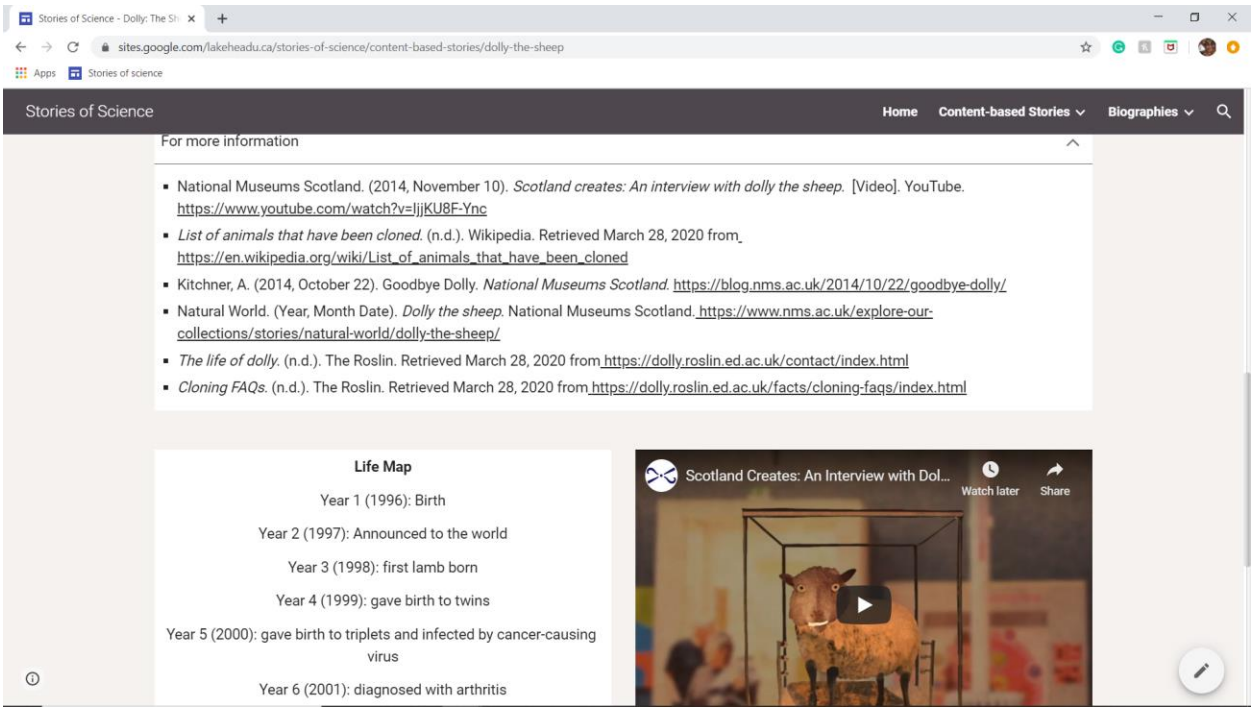

Figure 6: Screenshot from the website, resource material for the story of Dolly: The Sheep

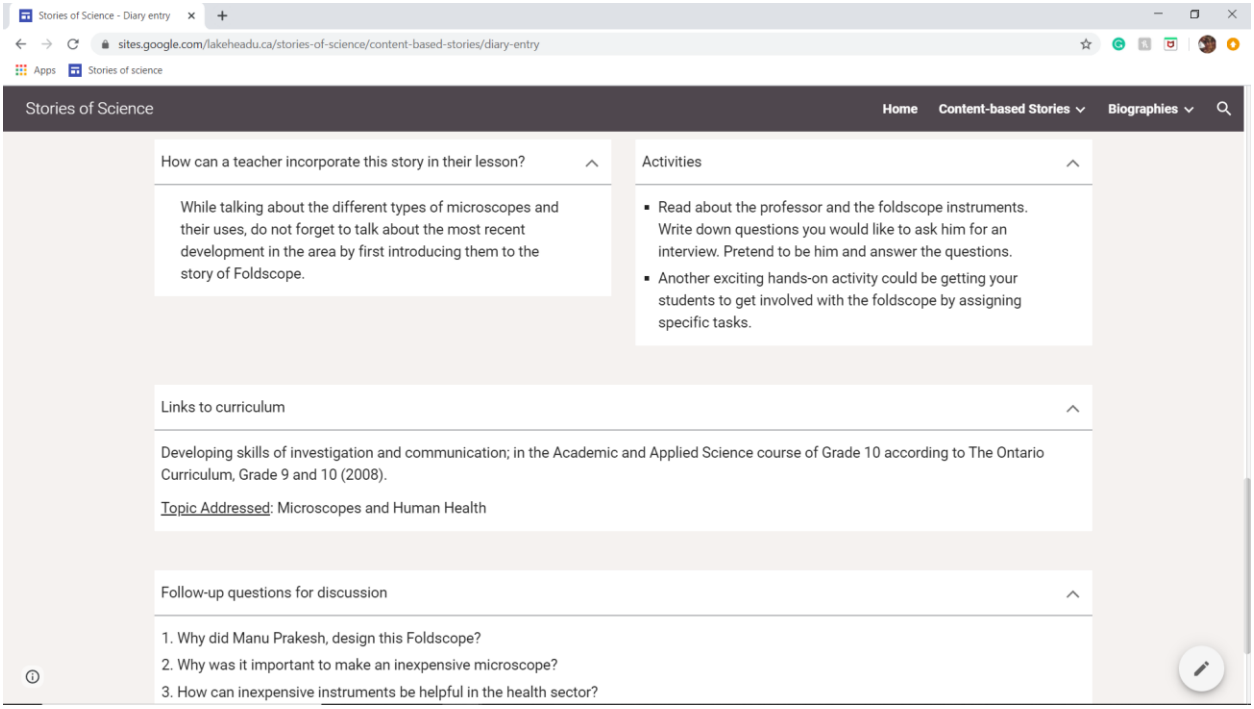

Figure 7: Screenshot from the website, additional information for the story of Diary Entry

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Appendix A: Biographies

Missile Man

Known as the “Missile Man of India” and “Peoples President”; A. P. J. Abdul Kalam served as an aeronautical scientist at the Indian Space Research Organization (ISRO) and Defence Research and Development Organization (DRDO) for nearly forty years before becoming the eleventh President of India.

Abdul Kalam was born in 1931 to Ashiamma, a housewife, and Jainulabdeen, a boat owner and Imam (worship leader) of the local mosque. His family was not financially affluent, and he had to sell newspapers during his early years. His day started at 4 am and finished at 11 pm. Values of determination, hard work and patience, taught by his father, were the foundation of his life and led him to attain the success that he is now known for.

He dreamt of being a fighter pilot but could not be one because Indian Air Force had 8 seats for pilots and he secured 9th rank. As a compromise, he went on studying physics and aerospace engineering and designing the missiles for the fighter planes. His first job at the Aeronautical Development Establishment (ADE) was to build a prototype of an hovercraft, which was beyond his teams' collective abilities. They tried and failed several times, and three days before the deadline to complete the project, his supervisor gave him a warning to complete the work or else there would be no funding. He knew that he would lose his job, well aware of the fact that the task he had been assigned was near to impossible. Upon receiving the notice, Kalam burnt the midnight oil and came up with the prototype, which was a surprise for him and his supervisor. The vehicle was then developed and the defence minister flew in it with Kalam as a pilot. This challenge was not the only obstacle he faced, yet he was patient and determined to achieve what he wanted and worked hard for it.

Kalam then joined ISRO, where he was head of the development of India's first rocket to launch a satellite, the SLV-III project and then went on joining DRDO. At DRDO he was associated with military missile development with his work on launch vehicle technology and development of ballistic missiles, leading to his being presented with the Bharat Ratan, India's highest civilian award in 1997 — he was also given a nickname of 'the Missile Man.' He also played a crucial role in India's Nuclear tests in 1998 and became the President of India in 2002. His term ended in 2007 but he continued to serve the nation as a visiting professor at the Indian Institute of Management in Shillong, Ahmedabad and Indore; as chancellor of the Indian Institute of Space Science and Technology in Thiruvananthapuram; professor of Aerospace Engineering at Anna University; and as an adjunct at many other academic and research institutes. He loved his work and never stopped working until he collapsed on 27th July, 2015 due to cardiac arrest while he was delivering a lecture at IIM Shillong.

Laboratory Confessions…

In the seventies, many people in Australia were suffering from gastric pains and could not be cured with conventional medicine. Their conditions were worsening due to the development of intestinal ulcers, causing internal bleeding, leading doctors to believe that nothing much could be done and so they treated patients with generic treatment.

Dr. Marshall, when studying the condition, stated that harmful microorganisms cause the ulcers, but he did not have any evidence to support his claim. Meanwhile, Dr. Robin Warren discovered a new bacterium (spiral-shaped) existing in an ulcer. With this discovery, they had a chance/hope to find solutions and started working on this bacterium. However, they were not able to grow the bacterium in the laboratory. All their attempts were in vain. Over a long Easter weekend in 1982, with Alexander Fleming's good fortune, they ended their bad luck when they found the growth of bacterium (by fluke).

Now they were able to cultivate the bacteria, but there were more obstacles. They grew the bacterium, but this time they failed to address Koch's Postulates. For the ones who do not know anything about Koch’s Postulates, these are like the immigration checkpoints when crossing international borders. With this failure, the evidence was of no use. It was essential to fulfill all the conditions, so they tried to study the effect of bacteria on mice and piglets to strengthen their argument/statement. They again were unsuccessful in infecting these animals.

Dr. Marshall became increasingly skeptical of prevalent scientific dogmas, which he lamented as "the illusion of knowledge," which restricted the progress of potentially ground breaking research. He couldn’t endure more rejection and made the drastic move in 1984 when, he drank a bacterial cocktail, which led to severe stomach inflammation for about two weeks. Seeing his condition/symptoms, his wife was terrified and worried that it would pass onto their

kids. But the beginning of good times started with his recovery leading to the publication of his findings in the world's leading medical journal, the *New England Journal of Medicine*. His certain faith in his research and his experience is represented in a comic called *Ulcer Tales*. Their work started a chain reaction in the study of *Helicobacter* in subsequent years. He, along with Warren, earned a number of awards over the years with the most prestigious being the Nobel Prize in Physiology or Medicine (2005). His ultimate dedication to research of *H. pylori* showed a great level of persistence and uprightness, which we should seek to accomplish through our work despite outside circumstances of prejudice and delusion.

Edith Clarke (Engineer)

Edith Clarke was a human computer (an individual crunching complex math formulas to help engineers in their work) for AT&T, an appropriate job for women at the time, when engineering was considered men's work and computing was women's work. In those odd times she dreamt of becoming an engineer. She was the first woman to graduate with a master's degree in electrical engineering from Massachusetts Institute of Technology. Even after her education she could not find a job as an engineer.

General Electric did not recognize her expertise and hired her to do calculations *for* engineers and to train other women. This did not stop her from working toward her dreams and passion. She invented a graphical calculator (equations with hyperbolic functions could be solved) and left her job at GE as they did not recognize her abilities as an engineer. After filing for a patent for the calculator in 1921 she travelled the world for a year. GE missed the patent rights to Edith's calculator because she was a part-time employee at the time she invented the calculator. Meanwhile, GE realized what they had been missing. So, when she returned, they offered her an engineering position.

Edith continued her work in both making calculations of equations easier and in improving the efficiency of transmission lines. She retired from GE in 1945 and then taught at the University of Texas for 10 years. Her work as an electrical engineer was respected and in 1948, she became the first female Fellow of the American Institute of Electrical Engineers.

Edith's story is proof that women can certainly do a "man's job".

Gerty Cori (Biochemist): Sometimes all you need is Love and Support

Gerty Cori was a biochemist and received a doctorate from the University of Prague, where she also found Carl Cori, her partner in life and science. These two were inseparable and worked together as a team. Carl would not accept a job where he had to stay away from Gerty, so in order to work together they left Prague and moved to Buffalo, New York, USA.

They started working on the mystery of how cells use sugars (carbohydrates) for energy. Today we read about the Cori cycle which tells us about the conversion of glucose to lactate in muscle and liver cells. After solving this mystery, they ran their own laboratory at Washington University, which was a hot spot for research in the field of biochemistry. This couple not only shared their workspace and life, they also shared a most prestigious award, the Nobel Prize in Physiology and Medicine in 1947 for their remarkable contributions.

Gerty developed a bone marrow disease but this did not stop her from working in the laboratory, and when she became too weak to get around, Carl would carry her where she needed to go. The love and support of Carl helped Gerty live her dream.

Hedy Lamarr (Inventor and Film Actress)

Most of us know Hedy Lamarr as a Hollywood actress but few are aware of her genius invention. She was born as Hedwig Eva Maria Kiesler in Austria. She dreamed of being an actress-and made it a reality, overcoming many obstacles to achieve this goal. When her husband came and tried to stop her from acting, she left him and fled to London where she met a big producer and got an acting contract from MGM and a new name. Besides acting she had a workshop where she tried her hand on inventing new things.

During World War II, when the National Inventors Council was accepting suggestions from civilians, Hedy got a chance to present her idea through which she could solve a problem faced by the US Navy. She suggested that she had invented a device which could be used to prevent signal jamming by the radio guided torpedoes and thus putting them off course. Following a conversation at a dinner party, Hedy developed the *frequency hopping spread spectrum* (FHSS), along with George Antheil, an avant-garde music composer. They figured out that radio signals can change frequencies in the same manner as a piano player changes notes. She registered a patent on her invention in 1942, but the US military did not use the device.

Hedy was disheartened but did not lose hope. She used her fame to raise money in war bonds to help the military. FHSS was finally used in 1962 when the military found that it is an important tool to control torpedoes. FHSS is not only limited to controlling torpedoes but it is the foundation on which modern day technology like smartphones, GPS, and Bluetooth devices work. For this invention she is now recognized in the National Inventors Hall of Fame.

Jane Cooke Wright (Oncologist)

In the early 1900s a cancer diagnosis was considered to be a death sentence. Doctors were working on finding a solution. A young woman named Jane Cooke Wright, after graduating from New York Medical College, started working at Harlem Hospital on cancer cells. Her dedication to finding effective treatment for cancer lead to the development of new, time-saving technologies to treat cancer. She proposed testing chemotherapy drugs on cancerous tissue from the patient rather than the patient directly, which allowed her to create the most effective treatment for the patient.

She also invented a way to treat hard-to-reach tumors in a less invasive manner than the contemporary treatment of surgical removal of the organs. At the time when there were few African American doctors and fewer women, Jane, at the age of 33, was a head of the cancer research center and leader in the field of oncology. She changed the way that cancer was treated forever and was co-founder of the American Society of Clinical Oncology. She became the dean of the New York Medical College and was the first woman president of the New York Cancer Society. Like her grandfather and father, Jane was an excellent doctor. She added to this family legacy by also becoming a forerunner for women in medicine.

Esther Lederberg (Microbiologist)

Esther Lederberg was a smart woman and an excellent storyteller which allowed her to present her ideas when they were not heard otherwise. She studied genetics at Stanford University and received a master's degree in genetics in 1946 and married Joshua Lederberg (a molecular biologist) the same year. After this she earned her doctorate from the University of Wisconsin and studied bacteria along with Joshua.

While studying *E. coli* bacteria cells she discovered a new type of virus that infects the bacterium (Lambda phage) and further helped in bettering the understanding of RNA, DNA and diseases such as herpes and tumor virus. She also created a new and a faster way (replica plating) to study mutations in bacteria. This also helped in easy identification of living and dead bacteria and further helped her team to study bacterial resistance to antibiotics. This work led to Joshua's winning the Nobel Prize in 1958. Unfortunately, Esther was left behind in the male-dominated world. This did not affect her work and she loved to work at the university, becoming the director of the Plasmid Reference Centre and continuing her research—even after she officially retired.

Resources

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Appendix B: Content-based Stories

Diary entry of a kid

Date: 3rd February 2020

… Science nerds in the class were excited about the person coming to our class this morning but I could not understand their excitement. For me, it will be another boring lecture filled with uninteresting theories and facts …

Date: 4th February 2020

…This morning our teacher escorted the guest speaker “Manu Prakash” to our class and introduced him to our class. A young man was wearing a jacket with his backpack, looking like one of us. He then pulled out colored papers from his backpack, keeping one to himself and distributed others among us and gave one to our teacher. The sheets had a few cut-outs and instructions to make folds. It was a fun activity, and I was happy because it was better than sitting in a dull and monotonous science classroom. Some students were surprised that instead of talking about real microscopes, he was teaching us to make origami microscopes. When everyone was finished making the origami microscope, Manu Prakash said that it is a 'foldscope,' an original and working microscope made of paper and material costing 97 cents. My friends and I thought that he is joking, and everyone laughed, as it was not close to the image of the microscope which is there in our book. When one of the students asked him a question about the lens, he then pointed out at the tiny hole in the center and that it is a lens and told us to look through it. The girl sitting next to me said, 'I have black things in my hand, a lot of them.' I was astonished, and the first thing I said was 'OH MY GOSH!' I could see the tiny things which were not visible otherwise.

He then showed us the video clip that he recorded on his smartphone camera lens by attaching it to the foldscope. It was like a scene from an alien horror movie, where a hairy mosquito was laying eggs, and one could also see the mosquito's moving organs…

Everyone in the class was amazed and surprised, including our teacher.

Dolly- The Sheep

"A clone is a living organism, which shares the same genetic information as another organism." It may or may not share the same characteristics as they are affected by the environment that they grow up in. They do have the same DNA, but they may look or behave differently from their parent. Clones are found in nature, and scientists can create one too.

Scientists at The Roslin Institute were working on developing a better method for producing livestock and learning about the changes in the cell during the development. Different people were involved, including scientists, embryologists, surgeons, vets and farm staff under the supervision of Professor Sir Ian Wilmut. This team's work led to the creation of an organism which was the first of its kind, Dolly – The Sheep.

She was a clone of a six-year-old Finn Dorser sheep. Sir Ian took the nucleus from the mammary gland of this sheep and placed it in another cell, which did not have one. The latter cell was an egg cell from a Scottish Blackface Sheep. This combination of cells produced an embryo. After a few days in a test tube, Dolly (embryo) was transferred to a surrogate mother (Scottish Blackface Sheep). She was born on 5th July, 1996. It took eight months after her birth for the scientists to compile their results and publish them. With this publication, Dolly was announced to the world on 22nd February, 1997. With this announcement came 3000 phone calls to The Roslin Institute from around the world.

Scientists and the public were astonished and surprised to hear about the cloned sheep and its existence. This astonishment was due to fact that she was the first mammal to be cloned from an adult cell. Her birth was proof that specialized cells could be used to produce clones and this fact opened up possibilities in both biology and medicine. However, she was not the first

mammal to be cloned, this honour belongs to another sheep born in 1984. She was cloned from an embryo cell. Now you know why Dolly was so special.

Dolly led a normal and healthy life at The Roslin Institute until the birth of her triplets and a virus outbreak in 2000. This virus infected many sheep at the institute and Dolly was one of them. Marking the end of her healthy days, the following year she was diagnosed with arthritis when farm staff noticed her stiff walk and treated her for it, but this was not the end. Over the course of the following year she developed a cough as a result of a tumour in her lungs, which was not curable. Then the institute decided to put Dolly to sleep on 14th February, 2003 in order to avoid the risk of her suffering. Now she rests at the National Museum of Scotland in Edinburgh and is the museum's most popular exhibit.

Dolly was also important because it fostered the idea of having a clone or a duplicate, a concept often pursued in science fiction. Dolly's birth also contributed to the interpretation that it might be conceivable to have a clone of a human being. Similarly, "plans to clone extinct species have attracted a lot of publicity, but at present, such ideas must remain, like *Jurassic Park*, firmly in the realm of fiction."

Notorious cells

Like students, all cells also undergo various tests; first (sessional exam) the quality assurance test, second (mid-term exam) the duplication test and third (final exam) the alignment test. They are also given a second chance to appear for the tests. Cells are divided into three types based on their performance on tests.

Those cells that demonstrate that they have sufficient knowledge (proteins and enzymes for replication) in the "sessional exam" are allowed to replicate their DNA. The ones failing the test are given a second chance. These cells will go back and prepare the proteins and enzymes required and then undergo a check. Once they are of high enough quality, they can now replicate.

After replication of DNA, they undergo "mid-term exams" where they are checked for their ability to duplicate. Again, some cells will fail, as it is challenging to produce an exact copy of what is learned. It doesn't matter that they fail this second test as they are given another chance. They are given time to prepare and amend their mistakes and once they clear this test, they can now divide.

Finally, when they are dividing, they are given a "final exam" before they divide their content equally among two daughter cells. For this test, chromosomes in the cells have to stand in a straight queue. The cells passing this test divide and result in two daughter cells and the ones that do not pass are given a second chance.

The cells not passing the tests, even in the second attempt, are sent to jail and are sentenced to death. A bit harsh but important for maintaining healthy cells. Sometimes some cells act clever and find shortcuts to the end. This means that they skip their detention and their chance to make amends, and they divide. These notorious cells are called cancer cells. Just as

there is not any single reason why students sometimes misbehave, there are many reasons why cells make their control difficult.

Story of Smallpox eradication

A deadly and a contagious virus responsible for smallpox arose centuries ago. Smallpox can be traced back to a 3000-year-old Egyptian mummy and first epidemic during the Egypt-Hittie war in 1350 B.C. Since then smallpox made its way around the world via Egyptian merchants, and then through the Arab world with the Crusades, and all the way to the Americas and Australia through conquest and colonization. Three out of ten people infected would die leading to billions of deaths.

It was unbeatable as the earlier treatment of variolation was not successful and foolproof, because people died of infection caused by the treatment. It wasn't until the English physician Edward Jenner noticed something interesting about dairymaids leading to the modern-day solution. At the age of 13, while working with a country surgeon to learn the skills, he heard a dairymaid say, “I shall never have smallpox, for I have had cowpox. I shall never have an ugly, pockmarked face.”

Later on, as a physician, he realized that she was right; people who got cowpox didn't develop the deadly smallpox. Cowpox is a less virulent and gave immunity to farm workers. So Jenner decided to test whether the cowpox virus could be used to protect against smallpox. In May 1796, Jenner found a young dairymaid, Sarah Nelmes, who had fresh cowpox lesions on her hand and arm caught from the udder of a cow named Blossom. Using matter from Sarah’s pustules, he inoculated James Phipps, the eight-year-old son of his gardener. After a few days of fever and discomfort, the boy seemed to recover from cowpox. Two months later, Jenner inoculated the boy again, this time with matter from a fresh smallpox lesion. No disease developed, and Jenner concluded that protection was complete. His plan had worked. Jenner later used the cowpox virus in several other people and challenged them repeatedly with smallpox,

proving that they were immune to the disease. With this procedure, Jenner invented the smallpox vaccination.

Unlike variolation, which used actual smallpox virus to try to protect people, the smallpox vaccination used the far less dangerous cowpox virus. The medical establishment, as cautious then as now, carefully looked over his findings before eventually accepting them; they implemented vaccination and prohibited variolation in England in 1840. After large vaccination campaigns throughout the 19th and 20th centuries, the World Health Organization certified smallpox was eradication in 1979. Jenner is forever remembered as the father of immunology, but let's not forget the dairymaid Sarah Nelmes, Blossom the cow, and James Phipps, all heroes in this great adventure to develop a vaccination that helped eradicate smallpox.

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