Welcome to Mars: Fictional placemaking for the meaningful learning of biology

Emmeline Hoogland
6328296

Supervisor: Dr. M.H.J. Ummels

Research Project for MSc Science Education and Communication

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Abstract: The aim of this design-based research was to explore the use of fictional places as meaningful contexts for learning. The design was based on design principles distilled from four theories and practices: (1) place-based education; (2) communities of practice; (3) imaginative teaching; and (4) story-based learning. These design principles are the foundation of fictional placemaking, which allows for the establishment of an emotional connection to contexts created and used to teach concepts and skills. A lesson series was created to evaluate the contribution of the design principles to the meaningful learning of system thinking. Student groups had to design societies living in domes on Mars. The lesson series was taught in one ninth-grade class (Dutch 3 VWO, 28 students). Data was collected through student projects, concept maps, a placemaking exercise and a questionnaire in a period of one month. The analysis of the data showed that five out of six groups reached the highest level of the system thinking hierarchy model after completing the lesson series. It also showed the establishment of an emotional connection to the fictional place, an engagement with the story told and the use of imagination. These findings illustrate the potential of fictional placemaking to create contexts that promote the meaningful learning of biology.

1. Introduction

Storybooks can capture our imagination, making our brains create whole worlds out of nothing more than written words. We establish connections with the players, attachments to places and sometimes feel like we are part of it all. Stories have meaning to us. Science also tells a story, albeit in a different way. It is the story of concepts that explain natural phenomena, and of the methods used to generate new knowledge. It is, however, also a story that many secondary school students deem not relevant to them (Basu & Barton, 2007), resulting in a reported decline in interest (Aikenhead & Elliott, 2010; Prokop & Fančovičová, 2017) Many students use rote learning, because they do not feel engaged with science, sometimes experiencing it as a foreign culture trying to alienate them from their own cultural identity (Aikenhead & Elliott, 2010; Aikenhead & Jegede, 1999). The goal of science education is two-fold: to increase people's scientific literacy, and therefore empowering them to make critical decision on matters concerning them and to draw young talented people to science to keep up with the accelerating need for innovation (Wals et al., 2014). Recently, the scientific literacy framework was reconceptualized, to keep pace with the increasingly changing world. It now promotes an internalization of systematic thinking and emphasizes the need to build character and values that support the making of choices that contributed to a sustainable planet (Choi et al., 2011). Currently, science education does not seem to contribute to this, with a declined interest among students and adult's scoring low on standardized scientific literacy tests (Stocklmayer & Bryant, 2012). This is not only a problem from a global perspective, it also means that people do not have the key competencies and skills needed for daily life in the 21st century (Binkley et al., 2011).

The alienation of some students from the scientific paradigm can be traced to the Enlightenment, as it was then that science started working towards separating space from place, culture from nature, creating a distinctive narrative of placelessness (Agnew, 2005). Science hereby helped the advancement of Western Civilization by providing a "terra nullius: an empty land awaiting a colonial history and economy" (Johnson, 2012:829). Nowadays, Science is said to be applicable to every realm of human life (Stenmark, 1997). It has, however, placed itself above the everyday, severed from place, where knowledge can be generated and taught without connection to people, landscape, narratives, and place (Merchant, 1995). The concept of place encompasses the physical, emotional and social connections people have with a space in a dynamic temporal relationship (Johnson, 2012). This placelessness cause some students' to experience a discontinuity between their lifeworld's and the science classroom (Bronkhorst & Akkerman, 2016). The Scientific paradigm of placelessness and universalism (Aikenhead & Elliott, 2010) is something student’s find difficult to connect with, resulting in limited interaction between different knowledge systems and low learning efficiency (Aikenhead & Jegede, 1999).

When there is an emotional connection with what is to be learned, the integrating of new knowledge within cognitive structures becomes easier (Novak, 1985; Driscoll, 2005). Aiding the establishment of emotional connections can therefore be an important tool in the meaningful and successful learning of science (Immordino-Yang & Faeth, 2010). The aim of this research is to design a fictional placemaking approach that increases student’s interest and learning of science, by putting place back into science and thereby enhancing emotional engagement with the abstract scientific concepts introduced.

Science education researchers agree that system thinking is important for the meaningful learning and understanding of science (Assaraf & Orion, 2010; Penner, 2000; Riess & Mischo, 2010). System thinking focuses on understanding a system, by recognizing the interconnectedness of its separate parts and their working together to create the whole (Assaraf & Orion, 2005). It helps the student to see the bigger picture in a larger context (Tripto et al., 2016) and is the foundation for understanding and solving sustainability issues (Wolf, Smit & Hurkxkens, 2018). System thinking is considered a higher order thinking skill, which some researchers arguing that students cannot do this before the high school level (Boersma, Waarlo & Klaassen, 2011), while others claim that it is possible to develop at an elementary school level (Assaraf & Orion, 2010). Whatever age it is first taught, assessment shows that both students (Arndt, 2006) and adults (Riess & Mischo, 2010) struggle with using these skills to understand complex systems. To help with the learning of system thinking skills in a meaningful way, a fictional place will be constructed to serve as the context for learning. Section two will start with the theoretical framework in which this research is situated, which leads to the formulation of the design principles in section three. This is followed by section four outlining the methods used to evaluate the design principles’ contributions and to establish the level of system thinking of the students, section five states the results of this, and the discussion in section six will answer the following research question: How does ‘fictional placemaking’ stimulate the meaningful learning of system thinking by middle-school aged students?

2. Theoretical Framework

This section will discuss the theories on which fictional placemaking is based. It starts with cultural-historical activity theory which is the foundation for place-based education (PBE) and community of practice theories, which are discussed after. This is followed by a brief discussion of context-based learning, which leads to an identification of the limitations of both this method as well as PBE.

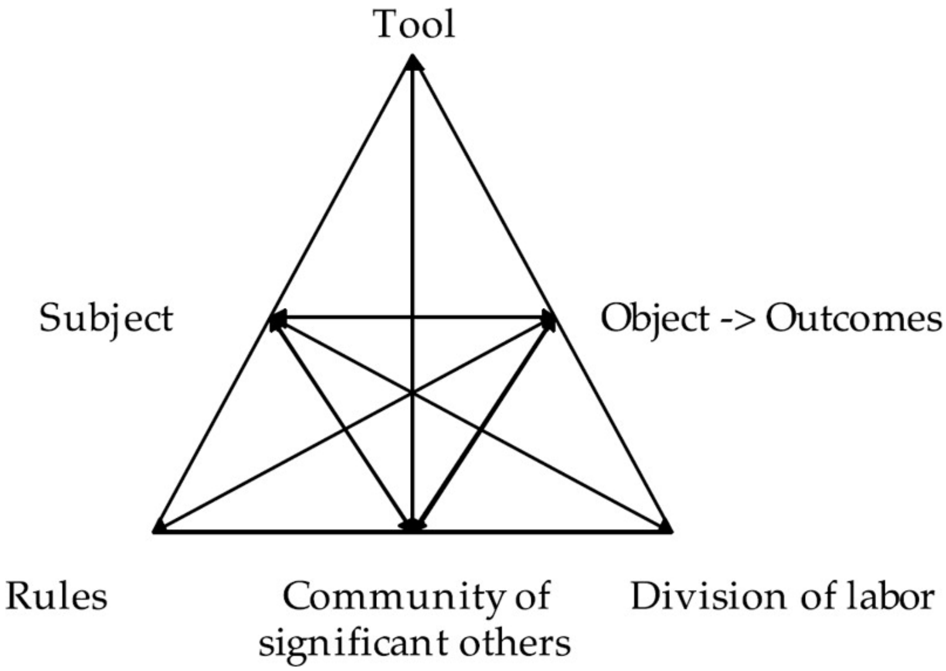
2.1 Cultural-Historical Activity Theory

This research is based on the three core ideas of Vygotsky’s cultural-historical activity theory (CHAT), (Vygotsky, 1978):

1. Humans learn by doing in a collective way, in which they communicate through their actions
2. Humans make, use, and adapt different tools to learn and communicate
3. Communities are central to the process of making meaning, and therefore all learning.

This core ideas are operated in CHAT’s model of an activity system (figure 2.1), which recognizes six elements dynamically related (Foot, 2014). Learning results in and from structural change in the activity system in which the child is participating (Lourenço, 2012). This learning becomes meaningful when the new knowledge is integrated with existing knowledge structures, while constructing and maintaining an emotional engagement with the concepts to be learned (Novak, 1985) Using CHAT can help to identify the activity systems at work and the motives, goals and needs of all participants and stakeholders within them (Lazarou, 2011). This can aid the construction of an inclusive design, catered for the different stakeholders, allowing all students to get involved with the classroom activity system (Roth & Lee, 2007). Moreover, the third core idea is the basis of the importance of communities of practices for learning of and engagement with new knowledge.

Figure 2.1: Activity System Model (Engeström, 1987, p. 78)



2.2 Communities of Practice

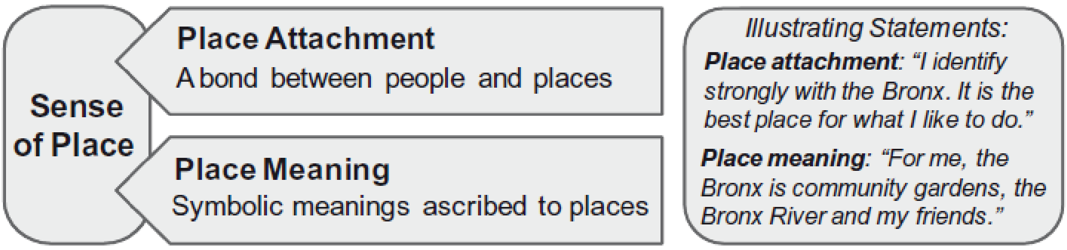
Following CHAT, people create meaning and engage in learning through communities of practice. In these members come together to negotiate and engage with their shared goals and to develop an understanding of the world (Wenger, 1998). Through engagement with such a community, people construct a collective and individual identity, making it part of the geographical 'self', which is our understanding of our own existence and difference from others (Castree, Kitchen, & Rogers, 2013). Through engagement with the community, both learning and acceptance happens (Paechter, 2003). This takes place both globally through the collective identity, and locally by the direct interaction with the local community of practice operating within the activity system (Wenger, 1998). Students are members of multiple communities of practice at one time, which leads to dynamically interacting and evolving boundaries (Akkerman & Van Eijck, 2011). These boundaries can aid learning by providing a space for reflection and identification with others, while being aware of the difference between ourselves and the 'other' (Akkerman & Bakker, 2011). The use of communities of practice to enhance learning and engagement with science has been an important element of the success of citizen science. Citizen science projects have been credited with positively influencing people's attitudes towards science, while collecting scientific data (Price & Lee, 2013). The sustained commitment to a project is strongly correlated with the sense of being part of an active community of people with shared interests, which leads to a feeling of personal empowerment (Nov et al, 2014). Constructing a community of practice within the classroom's activity system, could lead to increased engagement with the scientific concepts to be learned. Principles from place-based education can be used to establish and strengthen this community.

2.3 Place-based education

CHAT recognizes that people and places co-construct each other through dynamic relationships (Coughlin & Kirch, 2010). The concept of place is shaped and constructed by the interactions between a community and its environment throughout cultural-historical time (van Eijck & Roth, 2010). Place-based education (PBE) aims to support a sense of place, while providing a localized hoenvironment (Smith, 2007). The sense of place is a product of becoming attached to a place and escribing meaning to it (figure 2.2).

In the fast pace of our globalized world it can be difficult to apply theory to practice, global to local and the real lifeworld to the abstract one of science. PBE aims to foster a localized community of

Figure 2.2: Components of a sense of place (Kudryavstev et al, 2012)



practice thereby increasing people's sense of place (Semken & Freeman, 2008; Sun, Chan, & Chen, 2016). It uses learning activities that enhance the relationship with the community, leading to genuinely engaged students (Vansteenkiste et al, 2004). Studies in the USA and Canada have shown a positive effect on student's motivation for and engagement with learning (Powers, 2004), an increase in a feeling of agency leading to sustained interest (Basu & Barton, 2007) and higher rates of factual knowledge of science (Buxton, 2010). Successful PBE school projects involved solving a murder using place-based augmented reality through the process of scientific enquiry (Squire & Jan, 2007), collaborating with Indigenous Elders to create cross-cultural school science (Aikenhead & Elliott, 2010) and projects concerning human well-being and environmental injustice (Buxton, 2010). All projects reported increased student engagement, motivation to act and theoretical knowledge of science.

However, the curriculum is filled with concepts that cannot be easily tied or learned through PBE, especially as this is not the goal of this type of education. Using the place people live does not automatically lead to connecting formal education to the lifeworld of the students and will therefore not always mitigate the problems of discontinuity. Moreover, PBE uses only one context; the local environment and community, limiting the range of concepts that can be taught. Context-based learning does not have this limitation, as the contexts used are not necessarily localized.

2.4 Context-based learning

Context-based learning uses meaningful contexts to frame concepts in order to engage student's interest and engagement (King & Ritchie, 2012). In this approach problems from real-world contexts are used to motivate students to want to discover the answers through goal-oriented activities (Wieringa, Janssen, & Van Driel, 2011). Moreover, it increases the perceived relevance of science education by using real-life contexts, highlighting the ways in which science can be used to solve problems or answer questions (Ummels et al., 2015). It places the learning of science within an activity-system, giving context to the placeless concepts of science. However, a context in which science is relevant to society, does not necessarily make it so for the students.

2.5 Fictional placemaking

Both context-based learning and PBE have their limitations in terms of engaging students in meaningful learning, which requires both organized knowledge structures and emotional engagement (Ausubel, Novak, & Hanesian, 1978). The context-based approach uses a variety of contexts to frame a multitude of scientific concepts. A context is a "realistic situation from students' own lives, from society or from professional or scientific practices" (Wieringa, Janssen & van Driel, 2011, p. 2439). When the context uses a situation from a professional or scientific practice, relevance for the student and therefore emotional engagement might be lower than required for meaningful learning. PBE establishes an emotional connection to the local place, increasing its potential as a meaningful context. However, the range of concepts that can be framed within this context is limited. Current teaching methods do not offer guidance for teaching abstract scientific concepts within a context that is emotionally engaging and connected to the student's lifeworld. This research fills that gap by formulating design principles for 'fictional placemaking', allowing teachers to frame abstract concepts within emotionally engaging and for the student relevant contexts. The design principles will be discussed in section three.

3. Design rational

The fictional place is used as a context for the meaningful learning of system thinking. The focus is therefore two-fold, on the one hand it is about integrating system thinking knowledge into cognitive structures, to promote learning efficiency (Driscoll, 2005). On the other hand, it focusses on the emotional connection with the material to be learned, to engage students and to make the learning truly meaningful (Anderson, 2018).The fictional placemaking design is based on imaginative teaching theory (Egan, 2005), story-based learning (Creswell, 1997) and PBE principles (Leopold, 1949) to construct a fictional context and support the establishment of communities of practice. From these theories the following four design principle were formulated:

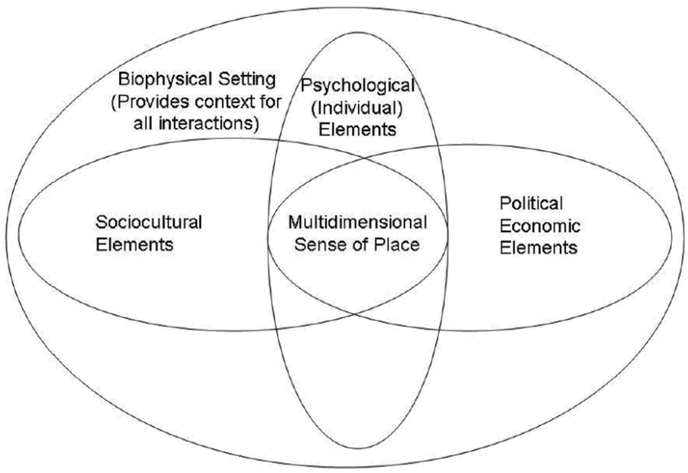
1. Build a 'sense of place' by using 'pedagogy of place' strategies.
2. Create opportunities for establishing a 'community of practice'.
3. Engage the imagination by using age-appropriate cognitive tools.
4. Frame the lessons within a narrative in which the students are active participants.

The following sections will discuss the development of the design principles from their respective theories.

3.1 Place-based education

PBE focuses on establishing an emotional connection to a place, making it a suitable context for meaningful learning. By using common elements of place-based education programs, these principles can be applied to foster an emotional connection to the fictional place. These common elements are: (1) the place is the foundation for the curriculum development, (2) students become the creators of knowledge, (3) students' roles and questions are central in determining what is studied, (4) teachers act as guides and co-learners and (5) boundaries between the place and the school systems are crossed frequently (Smith, 2002). The four dimensions of place (figure 3.1) are included into the placemaking, creating a world which the students can connect with. The fifth element of place, time (van Eijck & Roth, 2010), is included by focusing on Leopold's (1949) pedagogy of place. This approach involves (1) Wondering and questions, (2) Knowing the history and (3) Observing seasonal changes (Knapp, 2005).

Figure 3.1: Four dimensions of place (Airdoin, 2007).



3.2 Community of Practice

Placemaking is both an individual as a communal practice, with community-driven practices playing an important role in shaping places (Hou & Rios, 2003). It is therefore an integral part of the making of the fictional place. Moreover, as humans learn by doing collectively, the community of practice further supports learning, by allowing for a space to share ideas and work towards communal goals (Oxford, 1997). By providing students with a task that is to big and potentially complicated for the individual, while also given them shared goals, the establishment of a community of practice is stimulated.

3.3 Imaginative teaching theory

Imaginative teaching theory describes different cognitive tools, which children use to engage head, hands and heart to understand the world and construct meaning (Fettes & Judson, 2010). These cognitive tools are age-group specific and are formulated to engage their imagination, which could enhance active engagement, motivation and the incorporation of knowledge into existing structures (Egan, 2005). It creates a sense of wonder, which inspires and motivates children (Egan, Cant, & Judson, 2014). Imagination is a product of mental capacity and emotional engagement, and is enriched by opportunities to feel, think and experience (Fettes & Judson, 2010). Using the imagination, through the use of cognitive tools such as narrative, heroic qualities and collaboration with a community, powerful learning events can occur, as this matches the primate style of learning (Van Der Aalsvoort, 2014). It can specifically be used to aid placemaking, which is strongly influenced by emotional engagement, active cognition and a 'sense of possibility', which is related to wonder (Fettes & Judson, 2010). Imaginative teaching theory provides the framework on which learning activities using specific imaginative cognitive tools are based.

3.4 Story-based learning

For this research the story-based learning method 'Storyline: Creating Worlds, Constructing Meaning', was used to provide a general structure to the lessons (Creswell, 1997). This method takes students through the steps of designing a story, in which characters, settings, objects and relationships are constructed and taken on a journey. This ties in with the common elements of PBE, as the students are central in determining the direction of the story and therefore what is to be studied. Story-based learning increases both motivation and self-efficiency, although it might lower learning gains (McQuiggan et al., 2008). Although narratives can put the knowledge into a relatable activity system, therefore providing a context and a way of talking about the topic (Solomon, 2008), it can result in a cognitive overload (Lester et al., 2014). Moreover, the nature of narrative is that there is an element of dramatization and often a lack of chronological order (Norris et al., 2005). This could lead to lower learning gains, as the students might not be able to separate concepts from contexts or put processes and events in the correct order (Glaser, Garsoffky, & Schwan, 2009). However, the benefits of story-based learning and communications are documented within the informal education, as narrative is frequently used to communicate science to nonexpert audiences (Dahlstrom, 2014).

The next section will discuss how the design principles were operated in the research design and how they have been evaluated.

4. Methods

4.1 Design

The 'Welcome to Mars' lesson-series initially consisted of four sixty-minute lessons and was developed using the before mentioned design principles. During lesson two it was decided to extent the series with one sixty-minute lesson to allow the students more time to develop their ideas. The main purpose was the completion of a group project, in which the students had to design a society living in domes on Mars, to construct a timeline highlighting important moments in their societies and to develop adaptations to their communities to prescribed changes in abiotic and biotical elements. The students were given an informational booklet on different examples of animal species adapted to challenging circumstances. The *first design principle* was operated by making the development of a timeline an important aspect of the assignment and by putting the students in charge of the creation of their pace and the knowledge necessary to design this. Following *design principle two*, the communities of practice, the project was done in groups formed by the students, which were given their own story to develop. The first lesson used a narrative to introduce the students to a timeline of human inventions, ending with highlights of the exploration of space and the message that they were all selected to become the founding people of communities on Mars. The timeline was used to introduce the students to this way of structuring events and to highlight the heroic qualities of humanity, one of the cognitive tools of imaginative teaching. The question 'what are necessary elements to support life?' was raised and an activity to explore related concepts was conducted to give the students a starting point for their projects. The first lesson was an elaboration of *design principle one, three and four.* The second lesson further developed the narrative by introducing problems with the domes, different for each group, resulting in changes in the abiotic and biotic elements and problems with communication with Earth. The students were told their societies were not able to make contact for 10,000 years and that there was no other option than to adapt to the new situation. The groups were asked to update their timeline and to make drawings of how their dome would look after communications were reestablished. This changing of the context is an elaboration of *design principle three*. The events were part of the narrative to keep the students engaged and to stimulate system thinking, as they had to determine the effects of the faults on the development of their society. The reversed happened in the fourth lesson; the adaptations to an unknown fault were given in the form of a letter and drawings with clues, and the students had to figure out what had happened. This element was used to assess the extent in which the students were able to apply their system thinking skills. During the final lesson, the groups presented their project by telling the story of the societies they had designed. Although the students did receive some direct instruction, guidelines, and prescribed events, it was ultimately up them to decide how they wanted to shape and design their domes and its history.

4.2 Research participants

The sample consisted of one ninth grade pre-university level (Dutch 3 VWO, mean age 14) class (N = 29, 6 male, 23 female). The ninth grade was chosen because it is both the first year of biology lessons and the time when the students must decide if they want to continue with the subject for their high school examinations. The class was a preexisting group of students, who were randomly put together at the start of the year. Due to scheduling, the lessons took place over a period of four weeks.

4.3 Instruments, data collection and analysis

Data collection and analyses followed a mixed-method evaluation design, to allow for an evaluation of the design principles in terms of their contribution to the learning of system thinking skills. (Collins et al, 2004; Euler, 2017). The student projects, supported by concept maps, a questionnaire, and a place-meaning exercise were used as data sources. These can be categorized in measuring what the students had learned and how each of the design principles contributed to this learning. Table 4.1 presents which instruments were used to evaluate each design principle.

Table 4.1
Overview of instruments connected to research elements

		Instruments				
		Student projects[1]	Concept maps[1]	*Student presentations*[1,2]	Questionnaire[3]	Place-meaning exercise[3]
What have they learned?	System thinking	X	X	X	X	
How did the design principle contribute?	Design principle 1 *Place-based*				X	X
	Design principle 2 *Community of practice*				X	
	Design principle 3 *Imaginative teaching*	X		X	X	X
	Design principle 4 *Story-based*	X		X	X	X

[1]: Done collectively
[2]: Not analyzed separately
[3]: Done individually

To keep the distinction clear, section 3.3.1 will start with elaborating on the instruments and data collection of what the students have learned, followed by the analysis in section 4.3.2. From section 4.3.3, the instruments and analysis of the how the design principles contributed will be explained.

4.3.1 Instruments and Data collections for what they have learned

The student projects were the main data source. Without much teacher input, the students had to design and develop their societies on Mars, which makes the student projects a reflection of their thought development and skills. The student presentations were not analyzed separately but used to support the understanding of the student projects if elements were not clear.

It was decided to use concept maps to visualize student's mental models and thought experiments after the final presentations (Moon, Johnston and Moon, 2018). With system thinking being a mental model, concept mapping externally represents the extent of the student's skills (Tripto, Assaraf & Amit, 2018). The concept maps were made collectively, to reflect the nature of the group project. The guiding question for the concept map was: How was your dome influenced by environmental factors? This to encourage students to summarize what they had been developing during the lessons series and connect individual elements. The difference in time students had for the project (300 minutes) and the concept map (twenty minutes) meant that the latter is only a rough representation of their mental models. Therefore, the concept map was used as a support and affirmation of the student projects, as it can not show the entirety of the project and the student's thinking.

The first question of the questionnaire (Appendix I) asked the student what they had learned from the lessons. This retrospective questioning was chosen instead of pre-testing, due to the fictional nature of the project, making it difficult to test something they had not developed yet.

4.3.2 Data analysis of the what

The student projects, concept maps and question one were analyzed using an adaptation of the system thinking hierarchy model (STH) as shown in table 4.2 (Aasaraf & Orion, 2005). Each level of the STH is hierarchical, with level A being a prerequisite for level B, and B for C (Evagorou et al., 2009). The elements within each level are not hierarchical, with a student being able to show six, without having shown five. Element seven of level C was part of the assignment, which is therefore less indicative of the student's level. For this element, the assignment in lesson four was used: if they had managed to figure out the environmental change that had caused the adaptations, element seven was scored.

Question one of the questionnaire was analyzed for the mentioning of elements from the STH model. The answers were scored per level of the STH. For example, a student mentioning alterations in organisms over time because of changing circumstances was scored as having learned level C.

Table 4.2
System thinking hierarchy model applied to student projects

	Project shows:	What was looked for	Student work examples (group 6)
Level A: System components	1. Components of a system	Separate elements mentioned, such as organisms, environmental influences, events etc.	Humans, animals, plants, vegetables,
Level B: Synthesis of system components	2. A system with simple relationships.	Simple connections between two elements, without temporal or hierarchical components. Because A, there is B.	Use of animals and crops that require limited light. For example: horses who can synthesis vitamin D themselves.
	3. A system with dynamic relationships.	Connections between two or more elements that are influenced by each other or a separate element. Because of the influence of A, B changes, leading to problems with C.	Cows and pigs will have difficulty walking because of vitamin D deficiency; therefore, they will need artificial insemination.
	4. Organization of components within a framework of relationships	Placing and connecting elements and relationships within an overarching structure. Because A, there is B, which combined with C and D, results in the availability of E.	Spatial organization of specialized domes and communities, to the extent that two new species develop (adapted humans and farmers)
Level C: Implementation	5. A system with matter and /or energy cycles.	Closed circle relationships between elements concerning matter or energy. A lead to B, which is broken down to C, of which A is made.	The recycling of materials to provide raw materials to make new products.
	6. Hidden dimensions such as social factors	The consideration of the larger picture and connecting changes and / or events to elements beyond the scope of the assignment. Because of the influence of A, B changes, leading to problems with C, which results in a chance in the management of the human society.	Design shows societal adaptations to living in the dark, such as use of different textures, so people do not get lost.
	7. Temporal thinking	Being able to construct the question, from a cryptic representation of the answer. A changed, so what happens to B? Cross-section and a cryptic drawing of the end product of B is given.	The development of two species of humans, one adapted to living in the permanent darkness (hairy hands, deformed bones, bigger ears, no eyes) and semi-darkness (cat eyes, big ears).

4.3.3. Instruments and Data collection for the contribution of the design principles

To collect data for the evaluation of each separate design principle the student projects, a place-meaning exercise and a questionnaire were used. To increase validity of the findings, multiple data sources were used for all design principles, apart from number two. During the student projects, the students were given a few pointers for the development of their story (design principle 3 and 4), such as mandatory events, and they were required to create a timeline of the history of the dome (design principle 1). The presence, content and depth of certain elements is indicative of the workings of the operated design principle. The student presentations were used if project materials were not entirely clear. The projects and presentations were done collectively, the rest individually.

The extent in which place-meaning was developed by the students was an indicator for the working of design principle one. This was partly measured by asking the students to describe three places or events in their dome that had special meaning to them. This is an adaptation of the place attachment instrument in which people rate different statements measuring place-meaning and dependence (Williams & Vaske, 2003). This adaptation was necessary due to the fictional nature of the places, making it a very individual experience which cannot be measured using a standardized instrument. Moreover, using an open-ended exercise allowed for the students to express themselves freely, which can reveal their meaning-making practices and values, without interference of an adult researcher, allowing for a richer data collection (McTavish, Streelasky & Coles, 2012). The questionnaire covered all design principles by using open-ended questions covering different elements of the design for the same reason.

4.3.4 Data analysis of the contribution of the design principles

For the analysis, each design principle became a single unit to analyze, which is commonly used as a strategy in design studies (Kali et al, 2009). For the place-meaning exercise an adaptation to the place-attachment scale (table 4.3) was used. The student answers were scored based on the presence of the elements on the scale. The student answers were also analyzed for indicators of design principles three and four, such as engagement with the story and use of imagination. The questionnaire answers were analyzed on the mentioning of elements from the place-attachment scale and by coding and grouping student answers on the enjoyment of elements of the project. These groups were then related to the applicable design principle.

Table 4.3
Place attachment scale elements

1. I feel (place name) is a part of me.
2. (Place name) is the best place for what I like to do.
3. (Place name) is very special to me.
4. I identify strongly with (place name)
5. Visiting (place name) says a lot about who I am.
6. (Place name) means a lot to me.

Student projects were analyzed for indicators of design principle three (imaginative thinking) by looking at the amount of work done beyond the project requirements and the degree of uniqueness of the events, drawings, and other materials. They were also used to analyze design principle four by looking at the extent in which students used and appropriated the narrative, by making it their own and adding additional elements, which indicates engagement with the story. Design principle two was evaluated by analyzing student answers on question six of the questionnaire for the mentioning of community of practice elements.

5. Results

5.1 What have the students learned

The results of the analysis of the degree of system thinking shown by the student groups in their projects and concept maps are presented in table 5.1.

Table 5.1
Analysis of student projects following the STH model

	Group / Element	1		2		3		4		5		6	
		SP	CM	SP	CM	SP	CM	SP	CM	SP	CM	SP	CM
Level A	1. Single elements	X	X	X	X	X	X	X	X	X	X	X	X
Level B	2. Simple relations	X	X	X	X	X		X	X	X	X	X	X
	3. Dynamic relations	X	X	X		X	X	X	X	X	X	X	X
	4. Organization within a framework	X		X		X	X	X	X	X	X	X	X
Level C	5. Matter / energy cycles		X	X		X		X		X		X	
	6. Hidden dimensions			X		X		X		X	X	X	X
	7. Temporal thinking	X	X	X		X	X	X	X	X		X	

SP = Student project
CM = Concept map
X = Present in the work

For level A all the groups named different system components in their project and their concept maps. All groups had at least two out three components of level B in both their projects and concept maps, with three out of six portraying all three. For example, multiple groups used the use of human feces to fertilize the land to enable the production of food, which can be categorized as a system with simple relationships. For level C, all groups succeeded in completing the assignment in lesson four and were therefore scored with element seven. For the other elements, five out of six groups had both element five and six in their projects. In two groups, element six was also present in the concept map. To summarize, all groups showed all elements of level B in their student projects, with one group showing all elements of level C. Although the concept maps do not support all these elements, every group had at least one element of level B in their map.

On an individual level the first question of the questionnaire provided a retrospective and self-reflective view of what the students had learned. Sixteen students (n = 25) mentioned that they had learned elements from level B or C.

5.2 How did the design principles contribute

In this section the contribution of each design principle to the learning outcomes are presented. The students were asked which lesson feature they thought contribute most to their learning. Their answers could be divided into different categories, related to the design principles (table 5.2).

Table 5.2

Mentioning of design principles in question two

Design principle	Category	Number of times mentioned[1]
1. Place-based	Timeline	3
2. Community	Not categorized	1
3. Imaginative	Story, changing of context, student-guided learning, designing the domes	23
4. Story	Story, changing of context, timeline, designing the domes	18

[1] Students could mention multiple elements

Most of the students thought that design principle three and four contributed to their learning the most.

5.2.1 Design principle 1: Place-based education techniques

To examine the effect of the place-based education techniques the questionnaire and the place-meaning exercise were evaluated on the mentioning of elements on the place-attachment scale. Student projects were not used, due to the individual experience of connection to place and the collaborative nature of the projects. Students were asked what they thought of the timeline activity, which was used to establish a connection with the place through knowing the history. The answers (N=25) indicated that 12 students enjoyed the activity, 5 thought it was difficult, 3 found it interesting, 2 did not like it, 2 said it did not add anything and the remaining 3 did not answer the question. The students' descriptions of important place were analyzed and scored using the place-attachment scale, to determine the extent of their attachment. Each description was scored for the element that was most distinctly present. The results are shown in table 5.3

Table 5.3

Results of place-attachment exercise

Element on scale[1]	Descriptions scored with element (n = 45)
1. I feel (place name) is a part of me.	9
2. (Place name) is the best place for what I like to do	10
3. (Place name) is very special to me	7
4. I identify strongly with (place name)	7
5. Visiting (place name) says a lot about who I am	7
6. (place name) means a lot to me	6

Most interesting were the instances in which students showed an emotional connection with their Domes on Mars. This example was scored with element two and shows a degree of empathy:

> *On that side of the dome you see the art studio. That is where people can make and craft stuff. So, people of Mars have something fun to do in their spare time. It means something to me because I also like making and crafting things. I like being creative, that is why I think the people of Mars should be able to do that too.*

Here the art studio is described as the place you can do arts and crafts. The student explains the importance for them and continues to relate this to the needs of the people of Mars. Empathy is seen as an important component of place-based education as it suggests an emotional involvement with the subject or place (Brown et al., 2019).

> *The laboratory, a place where people produce information for research. This place means a lot to me because it allows me to experiment. I have the nature of a scientist, and to have my own laboratory on Mars is like a dream come true. It feels like home to me.* (Translated from Dutch)

This is an example of element 9: Visiting this place says a lot about who I am, due to the mentioning of the nature of a scientist and the lab feeling like home. The use of the 'I' in relation to your surroundings indicated a more intimate relationship (Knapp, 2005). The use in this context suggests that an emotional connection with the fictional place has been established.

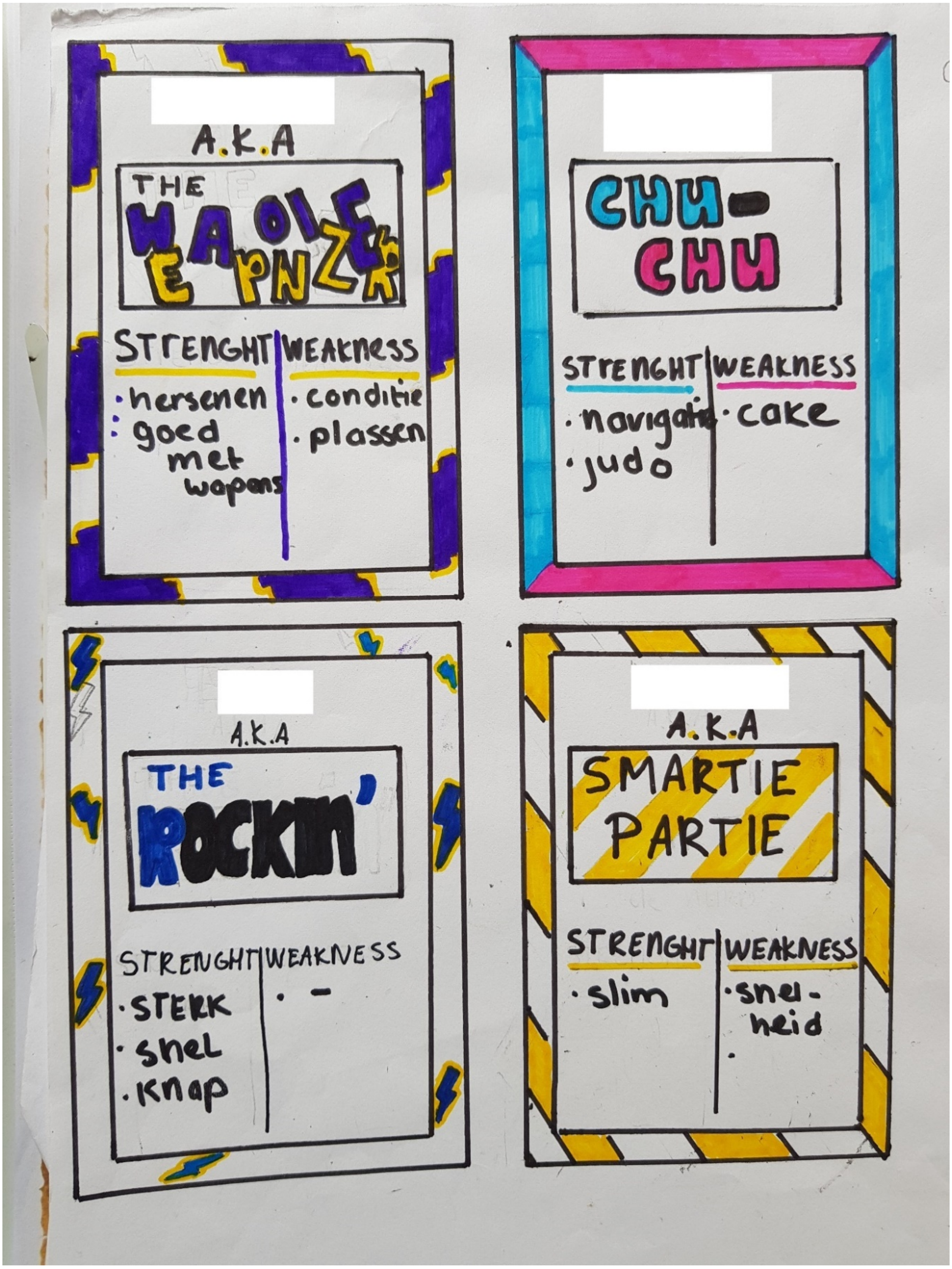
5.4.2 Design Principle 2: Community of Practice

Design principle two was covered by one question in the questionnaire, which asked the students if the groupwork had contributed to their learning. All students said that it had contributed to their learning. Sixteen students mentioned that it was because they could exchange ideas, which helped with their designs. Five students said that it helped to divide the tasks and share the load, the rest named personal preference or did not give an explanation

Design Principle 3: Imaginative teaching

The student materials, apart from the concept map, were evaluated for signs of engagement of the imagination. This is not clear-cut or easily assessed. All groups showed elements above and beyond the requirements given to them. Although there are similarities in the events added to the timelines, for example all timelines showed the event 'first baby born on Mars', all groups had unique elements in their timeline and projects. These included an Indian goose blood facility, the National after-hibernation-gardening day, and a variety of hybrid animal species. During the first lesson, there was a specific focus on the heroic qualities of humans, which is one of the elements of imaginative teaching theory. Work from two out of six groups showed heroic elements, such as citizen charts with strengths and weaknesses (figure 5.1) and events in the timeline heralding the bravery of the citizens.

Figure 5.1 Student working utilizing heroic qualities.



Design Principle 4: Story-based

After the project, all groups could tell a story about the development of their society and the adventures of its individuals. To an extent, this is reflected in the projects through events on the timeline and drawings showing changes over time. Four groups showed an overarching narrative, which was reflected in the timeline and the supporting drawings and other materials. One group without an overarching story did have a sub-narrative, about the quest for being able to safely inject geese blood to survive in low-oxygen circumstances. The other group had an extensive timeline, which told the story of developing the domes and establishing life on Mars, however this was not reflected in the supporting materials.

The changing of the context, such as the introducing of the faults in the systems, was mentioned by thirteen students as having contributed the most to their learning. Seven students mentioned that being in charge and figuring things out themselves contributed significantly. Both are important elements of story-based learning. Although it is not always explicit in the projects, different elements, in combination with how the students talked about “their” communities, does indicate that they made the story their own. This is also reflected in the individual place-meaning exercises, in which for example one student mentioned:

> *The place where all the cars / planes / helicopters / spaceships are parked of which I am the driver. The “chu-garage” which is my nickname and means driver of all vehicles.* (Translated from Dutch).

The student uses the first person to talk about a place that has meaning for her, as a character in the story. In ‘real life’ she is not old enough to drive, but in the story, she drives all sort of vehicle, even having a garage named after her. She has taken the initial story about becoming settlers on Mars, gave herself a role and constructed the world around her. This also indicates engagement of the imagination, which can both be a source and a result of the story.

6. Discussion and conclusion

The purpose of this study was to explore the use of fictional placemaking to stimulate the meaningful learning of system thinking, by establishing emotional connections to context created and used to teach concepts and skills. The ‘Welcome to Mars’ project was created based on the design principles formulated for fictional placemaking. These design principles were based on (1) place-based education techniques, such as creating histories of the fictional place, (2) community of practices to promote meaning making and learning, (3) imaginative teaching tools to engage the imagination and support emotional involvement and (4) story-based learning to promote engagement and relatedness to the constructed activity system and world. To evaluate if meaningful learning had taken place the system thinking hierarchy model was used to score the student projects, while the degree of emotional connection was assessed using a place-meaning exercise. The following sections will elaborate on the results and make suggestion on future improvements. Section 6.1 will focus on what the students have learned regarding system thinking skills, while 6.2 evaluates the design principles and the emotional connection aspects.

6.1 System thinking in the Mars Project

The first aim of the research was to establish what the students had learned meaningfully from the lesson series. This would manifest as students being able to use new knowledge to solve-problems in a changing context and represent these coherently (Mayer, 1992). The new knowledge consisted of system thinking skills, such as temporal thinking and considering dynamic relationships, and concepts related to possible adaptations to changing abiotic and biotic factors. Five out of six groups were able to display this knowledge to the highest level of the STH-model. Four students mentioned creative problem-solving as the main thing they had learned in the questionnaire. Although this is not an element in the STH, system thinking is often mentioned as being an essential part of problem-solving (Wolf, Smit & Hurkxken, 2018; Abidin, Jaafar, & Alwi, 2019). Mentioning an increase in problem-solving skills is therefore indicative in an increase in system thinking skills and of meaningful learning.

When researching the feasibility of system thinking on lower-secondary education classroom, Boersma, Waarlo & Klaassen (2011) concluded that this is only feasible if the temporal thinking aspect is omitted. However, in this study all students were able to meet the requirements for the temporal thinking elements of the STH. Research suggests that “the meaningful preparation of the required forward and backward thinking turned out to be difficult to achieve” (Verhoeff, 2003 in Boersma, Waarlo & Klaassen, 2011, p. 197). Part of the lesson series was the changing of the context within the story, guiding the students through forward thinking from the level of the organism to both that of the cell and the population. This was the preparation for the temporal thinking exercise in which the students had to think backward in time and upward from the level of the cell to that of the organism. The achievement of this level in the STH suggests that this preparation is possible, making the inclusion of temporal aspects in system thinking feasible.

6.2 Fictional placemaking in action

This design-based research was centered around how fictional placemaking can stimulate meaningful learning. To answer this question design principles were formulated, used to create a lesson series, and evaluated on their contribution to the learning that had taken place. The ‘Welcome to Mars’ series used a narrative to guide the students through the designing of domes which could house human societies on Mars. Different elements were inspired by an operationalization of the design principles, contributing to meaningful learning as mentioned in section 5.1. Each design principle contributed in a different way, with elements of each along with possible improvements discussed below.

6.2.1 Design principle 1: Place-based

Having an emotional connection with either the context or the material to be learned enhances learning efficiency and outcomes. While PBE can establish such connections with real place, fictional placemaking aims to do this with a fictional context. Almost everyone has experienced becoming emotional involved with fiction before. It isnot wanting a book or a series to end, because you have become attached to a fictional place. If everyone has experienced this, it must not be that difficult to establish. In a way it is not, although arguably it is more difficult if you want students, who have not chosen to be there or to watch that series, to connect to a place of fiction, while learning skills and concepts. In the case of fictional placemaking it is difficult because the place is not created yet; there is not a world ready for the student to read about or to watch, they must create it themselves. As the students created their societies, events and places became important to them:

> *The meeting*
> *I got selected for this Mars assignment with five others. I was soooooooooo nervous to meet them. To this day I am so happy with them. They are friends for live and I cannot wait to go on many other adventures with them* (Translated from Dutch)

Not only does this description combine both individual and community elements of place, it also describes the start of the history of life on Mars. As the history unfolded new elements of importance were created:

> *The Farmers Hospital*
> *This is located in the farmers dome, which has light four hours each day. If someone from the fifty domes needs a very specific operation which requires light, they come here. Here, farmers doctors who are specialized in the villagers can operate on them during the four hours of light. I think this is a very special and nice gesture of the farmers to the villagers. It is a nice gesture because it is voluntary. They help the villagers with some specific operations for which they need vision, which the villagers do not have.* (Translated from Dutch).

This description includes individual, sociocultural and environmental elements of place. It was produced through the development of the story, which includes the adaptational elements this student's group added, such as the creation of two different human species.

Although a connection to place was developed by most of the students, it is difficult to direct link this to PBE techniques. With students not getting to know elements of an existing place, including the history, but having to create them, arguably design principle one was not truly operated. Although students did consider elements of daily life at their place, such as sidewalks adapted to a blind population and raised beds to grow vegetables without having to bend down too much to conserve energy in a world adapted to malnutrition, there was not much attention given to the somatic experiences. This is described as getting to know a place through all the senses, at different times of day in all weather types (Fettes & Judson, 2012), and observing the effect of seasonal changes (Leopold, 1949). All the student projects were set in perfect sunny weather with none mentioning any seasons. Arguably, as they were designing the dome, they could have included an 'weather-element' making it forever sunny. However, there was no indication of the students considering weather patterns or seasons, even though this was included in the Mars section in their booklet.

With somatic experiences being the most difficult to achieve when talking about a fictional place, the operationalization of design principle one could be improved in two ways. The first is to specifically add a somatic element to the assignment, such as the creation of a 3D model in which textures are considered or adding a mandatory event set at night or during a specific season. Secondly, the introductory narrative could incorporate sensory experiences, such as wondering what people must have thought when they smelled fire for the first time or when they heard the noise of a spaceship lifting off. This could include mindfulness practices, as this has shown to help to experience a place more deeply (Deringer, 2017), although more research is needed to examine how to implement this in a fictional setting.

6.2.2 Design principle 2: Community of Practice

Groupwork alone does not create a community of practice but adding a common interest and the possibility for individuals to contribute their own intellectual expertise does (Pallinscar et al, 1998). The group nature of the project combined with the scope of the assignment and the creation of a shared history allowed for the establishment of such a community. Every member could contribute in their own way; the student who loves science could design the plant-based water recycling component, while the other who loved to draw could work on the aesthetics. Most of the students said that being able to share ideas in the group contributed to their learning,

The difference between a community of practice and a team is the type of partnership. Within a team it is task-driven, while in a community of practice it is about learning (Farnworth, Kleanthous & Trayner-Wegner, 2017). The students mentioning the sharing of ideas points towards a partnership based on learning; the group was useful for exchanges that aided their learning. However, the project assignments make the line between learning and task-orientation thin. The students had limited prior knowledge of the system skills required to complete the project, which made learning an essential element. When operating this design principles, make it about the learning by adding challenging elements above their skill level, to encourage the students to work and learn together.

6.2.3 Design principle 3: Imaginative teaching

Imagination is difficult to define, perhaps even more difficult to assess. There is no clear scale for the degree of imagination used, no real way of quantifying it. Egan (2005) suggests ways to evaluate the engagement of imagination by "Various kinds of information, including that derived from discussion, debate, artwork, and journal writing. Look for such things as emotional engagement, imaginative involvement, and the deployment of the cognitive tools that you have used and wish to develop" (p. 47). As previously mentioned, all student groups went beyond the assignment in terms of the story, events, and intricacies of the design. New human and animal species were imagined and drawn, a system allowing for the plants to be tended to even when the people were hibernating was designed and a broad array of technological designs to sustain cities and populations on Mars were developed. There is, however, one cognitive tool that was used, but not deployed by most of the groups. With the introduction narrative focusing on the heroic qualities of humans throughout time, and the project kicking off with "Congratulations all, you guys are the chosen ones to go and explore Mars', the expectation was heroism would be present in most projects. This was only the case in two.

Arguably, this does not imply that the students in the other groups were not imaginatively engaged; their work clearly showed signs of this. As did the individual place-exercises of these students. It does mean that the elaboration of *design principle three* did not entirely resonate with all students. The heroic qualities were part of the narrative, however, exercises in which students are encouraged to for example think of characteristics of a hero that would succeed on Mars could potentially stimulate students to utilize this cognitive tool more.

6.2.4 Design principle 4: Narrative

The timelines tell a story of development, of what makes a civilization and of obstacles encountered and dealt with. Although the design did not specifically ask the students to design characters, most groups did in some way. With the story developing and events unfolding, the students started to construct their narrative more. The projects changed from static designs and maps of domes, to a world with inhabitants that had specific needs, wants and issues to solve, with activity systems put into practice. As mentioned in section 6.2.1 focus on more somatic aspects could further increase the depth of these systems and the narrative, while also stimulating the students to further explore (a)biotic factors influencing life. This could also aid the development of the students' system thinking skills, as they add more elements and relationships to their mental models.

In conclusion, this design has shown the potential of fictional placemaking for the construction of meaningful contexts for the learning of system thinking skills and concepts. It has done so by stimulating the students' imagination by asking them to design their own societies on Mars, while also promoting the establishment of communities of practice and an emotional connection to place.

The entire project was set within a narrative, which gave the students a structure to base their own work and societies on. However, the design must give enough guidance for students to keep their imagination engaged and to stimulate them to explore all aspects of their world. In the end, the design principles, and the design itself are only a foundation for the students to build upon. It is all summarized by the question one student asked during the first lesson: “Miss, can we be the heroes of our own story?” Yes, you can.

References

Abidin, N. Z., Jaafar, I. A., & Alwi, A. (2019). The application of system thinking in solving complex problem: A case study of dengue transmission control policy. *AIP Conference Proceedings*, *2138*(1)

Agnew, J.A. (2005) Space: Place. In Cloke, P.J., Johnston, R.J. (eds) *Spaces of Geographical Thought: deconstruction Human Geography's binaries.* (pp. 81 0 96) London: Thousand Oaks

Aikenhead, G. S., & Elliott, D. (2010). An Emerging Decolonizing Science Education in Canada. *Canadian Journal of Science, Mathematics and Technology Education*, *10*(4), 321–338.

Aikenhead, G. S., & Jegede, O. J. (1999). Cross-cultural science education: A cognitive explanation of a cultural phenomenon. *Journal of Research in Science Teaching*, *36*(3), 269–287.

Akkerman, Sanne F., & Bakker, A. (2011). Boundary Crossing and Boundary Objects. *Review of Educational Research*, *81*(2), 132–169.

Akkerman, Sanne Floor, & Van Eijck, M. (2011). Re-theorising the student dialogically across and between boundaries of multiple communities. *British Educational Research Journal*, *39*(1), 1–13.

Anderson, R. C. (2018). Creative Engagement: Embodied Metaphor, the Affective Brain, and Meaningful Learning. *Mind, Brain, and Education*, *12*(2), 72–81.

Ardoin, N.M (2006) Toward and interdisciplinary understanding of place: Lessons for environmental education. *Canadian Journal of Environmental Education,* 11(1), pp. 112 - 126

Arndt, H. (2006). Enhancing System Thinking in Education Using System Dynamics. *SIMULATION*, *82*(11), 795–806.

Assaraf, O. B. Z., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *42*(5), 518-560.

Assaraf, O. B.-Z., & Orion, N. (2010). System thinking skills at the elementary school level. *Journal of Research in Science Teaching*, *47*(5), 540 - 563

Ausubel, D. P., Novak, J. D. (Joseph D., & Hanesian, H. (1978). *Educational psychology : a cognitive view*. Retrieved from https://books.google.nl/books/about/Educational_Psychology.html?id=17cdAAAAMAAJ&redir_esc=y

Basu, S. J., & Barton, A. C. (2007). Developing a sustained interest in science among urban minority youth. *Journal of Research in Science Teaching*, *44*(3), 466–489.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2011). Defining twenty-first century skills. In *Assessment and teaching of 21st century skills* (pp. 17-66). Springer, Dordrecht.

Boersma, K., Waarlo, A. J., & Klaassen, K. (2011). The feasibility of systems thinking in biology education. *Journal of Biological Education*, *45*(4), 190-197.

Bronkhorst, L. H., & Akkerman, S. F. (2016). At the boundary of school: Continuity and discontinuity in learning across contexts. *Educational Research Review*, *19*, 18–35. https://doi.org/10.1016/J.EDUREV.2016.04.001

Brown, K., Adger, W. N., Devine-Wright, P., Anderies, J. M., Barr, S., Bousquet, F., Quinn, T. (2019). Empathy, place and identity interactions for sustainability. *Global Environmental Change*, *56*, Buxton, C. A. (2010). Social Problem Solving Through Science: An Approach to Critical, Place-Based, Science Teaching and Learning. *Equity & Excellence in Education*, *43*(1), 120–135.

Castree, N., Kitchen, R., & Rogers, A. (2013). *A dictionary of human geography*. Retrieved from https://www.oxfordreference.com/view/10.1093/acref/9780199599868.001.0001/acref-9780199599868

Choi, K., Lee, H., Shin, N., Kim, S. W., & Krajcik, J. (2011). Re-conceptualization of scientific literacy in South Korea for the 21st century. *Journal of research in science teaching*, *48*(6), 670-697.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. *The Journal of the learning sciences*, *13*(1), 15-42.

Coughlin, C. A., & Kirch, S. A. (2010). Place-based education: A transformative activist stance. *Cultural Studies of Science Education*, *5*(4), 911–921.

Creswell, J. (1997). *Creating worlds, constructing meaning : the Scottish storyline method*. Heinemann.

Dahlstrom, M. F. (2014). Using narratives and storytelling to communicate science with nonexpert audiences. *Proceedings of the National Academy of Sciences of the United States of America*, *111 Suppl 4*(Supplement 4), 13614–13620.

Deringer, S. A. (2017). Mindful place-based education: Mapping the literature. *Journal of Experiential Education*, *40*(4), 333-348.

Driscoll, M.P. (2005) Meaningful Learning and Schema Theory. In: *Psychology of Learning for Instruction,* pp. 109 – 152. Boston: Pearson Eduction Inc.

Egan, K. (2005). *An imaginative approach to teaching*. Retrieved from https://www.wiley.com/en-us/An+Imaginative+Approach+to+Teaching-p-9780470928486

Egan, K., Cant, A. I., & Judson, G. (Eds.). (2014). *Wonder-full education: The centrality of wonder in teaching and learning across the curriculum*. Routledge.

Engeström, Y. (1987). *Learning by expanding: An activity-theoretical approach to developmental research*. Helsinki, Finland: Orienta-Konsultit Oy

Euler, D. (2017). Design principles as bridge between scientific knowledge production and practice design. *EDeR. Educational Design Research*, *1*(1).

Evagorou, M., Korfiatis, K., Nicolaou, C., & Constantinou, C. (2009). An investigation of the potential of interactive simulations for developing system thinking skills in elementary school: a case study with fifth-graders and sixth-graders. *International Journal of Science Education*, *31*(5), 655-674.

Farnsworth, V., Kleanthous, I., & Wenger-Trayner, E. (2016). Communities of practice as a social theory of learning: A conversation with Etienne Wenger. *British Journal of Educational Studies*, *64*(2), 139-160.

Fettes, M., & Judson, G. (2010). Imagination and the Cognitive Tools of Placemaking. *The Journal of Environmental Education*, *42*(2), 123–135. https://doi.org/10.1080/00958964.2010.505967

Foot, K. A. (2014). Cultural-historical activity theory: Exploring a theory to inform practice and research. *Journal of Human Behavior in the Social Environment*, *24*(3), 329-347.

Glaser, M., Garsoffky, B., & Schwan, S. (2009). Narrative-based learning: Possible benefits and problems. *Communications*, *34*(4), 429–447.

Hou, J., & Rios, M. (2003). Community-driven place making: the social practice of participatory design in the making of Union Point Park. *Journal of Architectural Education*, *57*(1), 19-27.

Immordino-Yang, M. H., & Faeth, M. (2010). The role of emotion and skilled intuition in learning. *Mind, brain, and education: Neuroscience implications for the classroom*, *69*, 83.

Johnson, J. T. (2012). Place-based learning and knowing: critical pedagogies grounded in Indigeneity. *GeoJournal*, *77*(6), 829–836.

Kali, Y., Levin-Peled, R., & Dori, Y. J. (2009). The role of design-principles in designing courses that promote collaborative learning in higher-education. *Computers in Human Behavior*, *25*(5), 1067-1078.

King, D., & Ritchie, S. M. (2012). Learning Science Through Real-World Contexts. In *Second International Handbook of Science Education* (pp. 69–79).

Knapp, C. E. (2005). The "I – Thou" Relationship, Place-Based Education, and Aldo Leopold. *Journal of Experiential Education*, *27*(3), 277–285. https://doi.org/10.1177/105382590502700307

Lazarou, D. (2011). Using Cultural-Historical Activity Theory to design and evaluate an educational game in science education. *Journal of Computer Assisted Learning*, *27*(5), 424–439.

Lester, J. C., Spires, H. A., Nietfeld, J. L., Minogue, J., Mott, B. W., & Lobene, E. V. (2014). Designing game-based learning environments for elementary science education: A narrative-centered learning perspective. *Information Sciences*, *264*, 4–18.

Leopold, A. (1949). A Sand County Almanac: With essays on conservation from Round River. New York: Ballantine Books

Lourenço, O. (2012). Piaget and Vygotsky: Many resemblances, and a crucial difference. *New Ideas in Psychology*, *30*(3), 281–295.

Mayer, R. E. (1992). *Thinking, problem solving, cognition*. WH Freeman/Times Books/Henry Holt & Co.

McInerney, P., Smyth, J., & Down, B. (2011). 'Coming to a *place* near you?' The politics and possibilities of a critical pedagogy of place-based education. *Asia-Pacific Journal of Teacher Education*, *39*(1), 3–16.

McQuiggan, S. W., Rowe, J. P., Lee, S., & Lester, J. C. (2008). Story-Based Learning: The Impact of Narrative on Learning Experiences and Outcomes. In *Intelligent Tutoring Systems* (pp. 530–539).

McTavish, M., Streelasky, J., & Coles, L. (2012). Listening to children's voices: Children as participants in research. *International Journal of Early Childhood*, *44*(3), 249-267.

Merchant, C. (1995). Reinventing Eden: Western culture as a recovery narrative. *Uncommon ground: Rethinking the human place in nature*, 132-59.

Moon, B., Johnston, C., & Moon, S. (2018). A Case for the Superiority of Concept Mapping-Based Assessments for Assessing Mental Models. In *Concept Mapping: Renewing Learning and Thinking. Proceedings of the 8th Int. Conference on Concept Mapping, Medellín, Colombia: Universidad EAFIT*

Norris, S. P., Guilbert, S. M., Smith, M. L., Hakimelahi, S., & Phillips, L. M. (2005). A theoretical framework for narrative explanation in science. *Science Education*, *89*(4), 535–563.

Novak, J. D. (1985). Application of advances in learning theory and philosophy of science to the improvement of chemistry teaching. *Journal of Chemical Education*, *61*(7), 607.

Nov, O., Arazy, O. & Anderson, D. (2014) Scientists@Home: What Drives the Quantity and Quality of Online Citizen Science Participation? *PLoS ONE,* 9(4)

Oxford, R. L. (1997). Cooperative learning, collaborative learning, and interaction: Three communicative strands in the language classroom. *The modern language journal*, *81*(4), 443-456.

Paechter, C. (2003). Masculinities and femininities as communities of practice. *Women's Studies International Forum*, *26*(1), 69–77.

Palincsar, A. S. (1998). Social constructivist perspectives on teaching and learning. *Annual review of psychology*, *49*(1), 345-375.

Penner, D.A. (2000). Explaining systems investigating middle school students' understanding of emergent phenomena. *Journal of Research in Science Teaching*, 37, 784–806.

Powers, A. L. (2004). An Evaluation of Four Place-Based Education Programs. *The Journal of Environmental Education*, *35*(4), 17–32.

Price, C. A., & Lee, H.-S. (2013). Changes in participants' scientific attitudes and epistemological beliefs during an astronomical citizen science project. *Journal of Research in Science Teaching*, *50*(7), 773–801.

Prokop, P., & Fančovičová, J. (2017). The effect of hands-on activities on children's knowledge and disgust for animals. *Journal of Biological Education*, *51*(3), 305–314.

Riess, W., & Mischo, C. (2010). Promoting Systems Thinking through Biology Lessons. *International Journal of Science Education*, *32*(6), 705–725.

Roth, W.-M., & Lee, Y.-J. (2007). "Vygotsky's Neglected Legacy": Cultural-Historical Activity Theory. *Review of Educational Research*, *77*(2), 186–232.

Semken, S., & Freeman, C. B. (2008). Sense of place in the practice and assessment of place-based science teaching. *Science Education*, *92*(6), 1042–1057

Smith, G. A. (2002). Place-based education: Learning to be where we are. *Phi delta kappan*, *83*(8), 584-594.

Smith, G. A. (2007). Place-based education: Breaking through the constraining regularities of public school. *Environmental Education Research*, *13*(2), 189-207.

Solomon, J. (2008). *Science Stories and Science Texts: What can they do for our students?* https://doi.org/10.1080/03057260208560178

Squire, K. D., & Jan, M. (2007). Mad City Mystery: Developing Scientific Argumentation Skills with a Place-based Augmented Reality Game on Handheld Computers. *Journal of Science Education and Technology*, *16*(1), 5–29.

Stenmark, M. (1997). WHAT IS SCIENTISM? *Religious Studies*, *33*(1)

Stocklmayer, S. M., & Bryant, C. (2012). Science and the Public—What should people know? *International Journal of Science Education, Part B*, *2*(1), 81–101.

Sun, Y., Chan, R. C. K., & Chen, H. (2016). Learning with Geographical Sensitivity: Place-Based Education and Its Praxis. *The Professional Geographer*, *68*(4), 574–583.

Tripto, J., Assaraf, O. B. Z., & Amit, M. (2018). Recurring patterns in the development of high school biology students' system thinking over time. *Instructional Science*, *46*(5), 639-680.

Tripto, J., Ben-Zvi Assaraf, O., Snapir, Z., & Amit, M. (2016). The 'What is a system' reflection interview as a knowledge integration activity for high school students' understanding of complex systems in human biology. *International Journal of Science Education*, *38*(4), 564–595.

Ummels, M. H. J., Kamp, M. J. A., de Kroon, H., & Boersma, K. T. (2015). Designing and Evaluating a Context-based Lesson Sequence Promoting Conceptual Coherence in Biology. *Journal of Biological Education*, *49*(1), 38–52.

Van Der Aalsvoort, G. (2014). *Educational and Child Psychology (Themanummer over spel)*. Retrieved from https://www.researchgate.net/publication/254776668

van Eijck, M., & Roth, W.-M. (2010). Towards a chronotopic theory of “place” in place-based education. *Cultural Studies of Science Education*, *5*(4), 869–898.

Vansteenkiste, M., Simons, J., Lens, W., Sheldon, K. M., & Deci, E. L. (2004). Motivating learning, performance, and persistence: the synergistic effects of intrinsic goal contents and autonomy-supportive contexts. *Journal of personality and social psychology*, *87*(2), 246.

Verhoeff, R. P. (2003). *Towards systems thinking in cell biology education* (Doctoral dissertation).

Vygotsky, L. S. (1978). Socio-cultural theory. *Mind in society*.

Wals, A. E. J., Brody, M., Dillon, J., & Stevenson, R. B. (2014). Convergence Between Science and Environmental Education. *Science*, *344*(6184), 583–584.

Wenger, E. (1998). *Communities of practice*. https://doi.org/10.1017/CBO9780511803932

Wieringa, N., Janssen, F. J. J. M., & Van Driel, J. H. (2011). Biology Teachers Designing Context-Based Lessons for Their Classroom Practice—The importance of rules-of-thumb. *International Journal of Science Education*, *33*(17), 2437–2462.

Williams, D. R., & Vaske, J. J. (2003). The Measurement of Place Attachment: Validity and Generalizability of a Psychometric Approach. *Forest Science*, *49*(6), 830–840.

Wolf de, M., Smit, E. & Hurkxkens, P. (2018) *Lesgeven over duurzame ontwikkeling*. Uitgeverij Garant: Antwerpen-Apeldoorn.

Appendix 1

Vragenlijst Welkom op Mars Koepel: ………

1. Kan je aangeven wat uit de concept map je in deze lessenserie hebt geleerd?

2. Welk onderdeel van de lessen heeft volgens jou hier het meest aan bijgedragen?

3. Hoe vond je het om een eigen koepel te ontwerpen?

4. Hoe vond je het een eigen geschiedenis voor de koepel te bedenken?

5. Denk je dat het verhaal bij heeft gedragen aan de lessen? Waarom wel of niet?

6. Heeft het werken in een groepje bijgedragen aan de lessen? Waarom wel of niet?