Content knowledge and scientific reasoning in an informal STEM environment and the influence of prior knowledge and design characteristics.

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Abstract

Engaging in the STEM subjects (Science, Technology, Engineering, Mathematics) becomes increasingly important in school since developing knowledge and skills about STEM-related topics enhances the development of 21st-century skills. However, students perceive STEM-related lessons in school as abstract, resulting in low motivation. Much STEM learning happens in informal STEM environments, such as museums or science centres, by sparking interest with authentic and exciting materials. A collaboration between schools and these environments could make abstract classroom STEM-related lessons more concrete and interesting. Studying to what degree this enhancement takes place can provide schools and informal STEM environments with information for collaboration. This study investigates fifth- and sixth-grade students' knowledge and scientific reasoning gains after engaging with an informal STEM environment and the effects of prior knowledge and the environment's design characteristics. This mixed-method study was conducted with 127 fifth- and sixth-grade primary school students from seven classes. A pre/post-test measured their knowledge and reasoning gains after a workshop in science museum Museumfabriek and the influence of prior knowledge on these gains. Engaging in the informal STEM environment was found to contribute to content knowledge and scientific reasoning. Still, the learning gains for the group with prior knowledge were smaller than for the group without prior knowledge. Seven focus-group interviews were conducted to understand the design characteristics that contributed the most to the content knowledge and scientific reasoning gains. The most frequently mentioned design characteristics were fun and interest, curiosity, personal experiences, complementing formal situations and hands-on activities.

Keywords: Informal STEM learning, prior knowledge, primary school

Contents

Introduction

The world increasingly counts upon 21st-century skills, such as adaptability, creativity, curiosity, and open-mindedness, and to meet these expectations, employers seek employees that possess these skills (Trilling & Fadel, 2009). To gain these skills, engagement in Science, Technology, Engineering and Mathematics (STEM) becomes increasingly important (OECD, 2018). Engaging with STEM topics can increase learners' knowledge about STEM and improve skills such as inquiry skills (Van Keulen & Oosterheert, 2016). This can allow learners "to think critically and creatively; to investigate, inquire, hypothesise, build theories and assess them; to problem solve and work in teams; and to develop curiosity and persistence" (Simoncini & Lasen, 2018, p. 366).

However, in schools, science can be seen as a distant and abstract subject causing a low motivation to learn about science concepts (Avraamidou & Roth, 2016). Many students experience STEM as a frustrating and boring due to the disconnection between the subject and the interests and experiences of the children (Mensah, 2013). This is alarming since STEM learning is increasingly important for developing 21st-century skills and acquiring jobs in the students' future (Kanematsu & Barry, 2016).

The majority of STEM learning happens outside of the formal classroom through a process called informal STEM learning (Allen & Peterman, 2019). Informal STEM learning can be defined as learning STEM across multiple designed settings outside of the classroom in a science-focused culture: where science education and social interactions congregate (Adams et al., 2012; NRC, 2015). Collaborating with informal science settings can enhance classroom science lessons and increase the time students are engaged in a topic (Marguerat & Bonello, 2022). Therefore, the European project Surrounded by Science aims to bridge the gap between informal learning and formal in-class learning by developing a science learning ecosystem where institutions can work together to provide science development of learners in all grades through learning experiences with peers and adults (Surrounded by Science, 2022). This can lower the threshold for schools to collaborate with informal STEM environments to enhance STEM learning by showing how other institutions impact students' engagement and scientific proficiency and how this can contribute to the knowledge and skills students learn in school (Surrounded by Science, 2022). These contributions could potentially lie within the development of concept knowledge and scientific reasoning, which will be studied in this study. To create this ecosystem, the project needs to understand how informal learning environments are experienced by the users and how they affect users' learning and motivation.

This study aims to contribute to the knowledge base of the Surrounded by Science project by focussing on the learning effects in an informal learning environment. More specifically, this study aims to shed light on the amount of content knowledge and scientific reasoning gained by primary school students of fifth and sixth grade in an educational workshop and guided tour in a science museum, a so-called museum lesson, and whether there is a difference between students that had prior knowledge before the museum lesson and students that did not. Moreover, this study aims to analyse the characteristics of the museum lesson that, according to students, contribute the most to the possible knowledge and reasoning gains.

Theoretical framework

Informal STEM-learning

When defining informal STEM learning, studies focus on the external characteristics, such as the environment where learning takes place, as well as internal characteristics, such as learners' experiences and internal incentives. When looking at the external characteristics, the NRC (2009) and Adams et al. (2012) describe informal STEM learning as learning in authentic science environments, wherein culture and collaboration are parallel to the real science context and offered in an open-ended and non-linear way. Avraamidou and Roth (2016) and CAISE (2017) add to this definition by describing informal STEM learning as learning that occurs outside of school in informal science environments, operating in many contexts and disciplines. Although the name suggests otherwise, these environments are "formally organised settings with specific science purposes" (Avraamidou & Roth, 2016, p. 23). The authors agree with Folkestad (2006), stating that the activity steers the learning that takes place.

For museums specifically, some specific external characteristics can be defined as well. Visiting a museum is a personal, social, and physical experience for the visitor. Therefore, museums have areas and exhibitions that foster learning about specific topics by letting the visitors understand and interpret the information through their own personal, social, and cultural lenses (Rabanaque, 2021).

Apart from the external characteristics, some internal characteristics of informal STEM learning can also be defined. The NRC (2009) described six strands of informal STEM learning that characterise internal processes in learners, namely that they:

1. Are excited, interested and motivated to learn about natural phenomena;
2. Can generate, understand, and remember concepts to explain science with models, arguments and facts;
3. Make sense of nature and physics by inquiry;
4. Reflect on their knowledge of science and their learning process;
5. Collaborating in science activities using scientific tools and language;
6. Develop a scientific identity as someone who understands and applies science.

These strands are the basis for successive literature on this subject. Folkestad (2006) calls informal STEM learning voluntary and self-regulated. This self-regulated learning is personal and guided by learners' interests, motivation, social skills, and awareness (Avraamidou & Roth, 2016). It is voluntary because there are no consequences of learners' (absence of) learning, relying entirely on intrinsic motivation, increasing the knowledge gained. In other words, it improves learning outcomes (Cerasoli et al., 2014, as cited by Allen & Peterman, 2019).

This self-regulated learning can also be found in literature about learning in museums specifically. Museum learning happens in the visitor's personal, social, and physical context to create meaning. Learning in museums differs per visitor and their expectations, experiences, and current knowledge (Chang, 2006). Museums promote scientific competency, including knowledge, learning strategies and skills in this personal, social, and physical context by encouraging interaction with the exhibition, other visitors, and guides (Rabanaque, 2021).

Combining these ideas, informal STEM learning is defined for this study as intrinsically motivated, self-regulated and voluntary learning that takes place in authentic, out-of-school environments wherein open-ended and non-linear activities enhance interest, motivation, and social competencies as well as learning outcomes. This definition accounts for both voluntary visits and obligatory visits as part of the school curriculum since learning during a mandatory visit is still voluntary.

Acquisition of content knowledge and scientific reasoning

To develop an interest of formal environments to collaborate with informal environments, it should be investigated what impact informal learning environments potentially have on visiting students. This study will look for an indication that the informal learning environment Museumfabriek, a museum around various topics on science and local history, fosters content knowledge and scientific reasoning skills that visiting students are expected to learn.

Several studies investigated the learning outcomes and gaining of content knowledge, knowledge about the topic presented in the environment, during informal STEM learning. Informal learning environments promote experimental and active learning of the presented content by enhancing personal connections with and interest in the given information (Khanaposhtani et al., 2018). Active learning is known for causing an increase in knowledge compared to traditional learning (Freeman et al., 2014). This active and experimental learning is encouraged in informal learning environments by offering hands-on learning experiences that promote collaboration, are authentic and contain inquiry-based learning (Khanaposhtani et al., 2018; NRC, 2015). Hands-on and collaborative activities contribute to active learning by increasing (joint) intrinsic motivation and timely attention. In addition, activities that provide authentic materials and experiences contribute to active learning by inspiring participants to learn about the presented topic as real scientists, connecting them to the practice of science (Khanaposhtani et al., 2018). It is also one of the strands of informal STEM learning (NRC, 2009).

Like content knowledge, scientific reasoning is one of the skills children learn in informal environments. Multiple studies have defined scientific reasoning as a skill consisting of identifying scientific issues, questioning, generating hypotheses, artefact construction, experimentation, data generation and evaluation, drawing conclusions and communication (Fischer et al., 2014; NRC, 2009; Norris et al., 2014; Opiz et al., 2017; Pedaste et al., 2015). Direct experience, as well as social interactions, are essential factors for constructing a cognitive framework, the development of which also develops the scientific reasoning ability of a child (Piaget, 1964, as cited in Gerber et al., 2001; Rogoff, 1990, as cited in Gerber et al., 2001). Informal learning environments are well suited for activities with direct experiences and social interactions to develop a cognitive framework (Gerber et al., 2001). It is also one of the strands of informal STEM learning (NRC, 2009). Increasing scientific reasoning among children can support lifelong STEM engagement (NRC, 2015).

Both content knowledge and scientific reasoning are thus accounted for in informal learning environments. The following paragraph will examine prior knowledge related to informal STEM learning to shed light on the learners' cognitive processes that contribute to gaining knowledge and skills.

Prior knowledge

Prior knowledge is defined by Jonassen and Gabrowski (1993) as "the knowledge, skills, or ability that students bring to the learning process" (p. 417). In this case, prior knowledge is the combination of knowledge, skills and abilities around STEM that connect to the learning goals of the informal learning environment. Educational research has long since found that prior knowledge is a strong predictor for developing a knowledge base of educational concepts or topics (Dochy et al., 1999; Khanaposhtani, 2018; Shapiro, 2004). In informal learning environments, too, research has shown that prior knowledge influences learning outcomes (Falk & Dierking, 2000, as cited in Falk & Adelman, 2003). For prior knowledge to influence learning outcomes, it should be activated, relevant and congruent (Brod, 2021). However, Simonsmeier et al. (2021) highlight that most previous studies focus on learning outcomes, not learning gains. This study focuses on these learning gains in content knowledge and scientific reasoning in the informal learning environment of a museum lesson and the influence of prior knowledge on this process to see whether having prior knowledge in any way influences the gains in content knowledge and scientific reasoning by fifth and sixth-grade students.

Design characteristics of informal STEM learning

Design characteristics are defined by Ross (2022) as “Design attributes or distinguishing features that pertain to a measurable description of a product or service” (p. 53). For this thesis, design characteristics are the measurable features of informal STEM learning environments. Based on a literature and field study, the project Surrounded by Science came up with two general design characteristics of informal STEM learning, namely that the learning environment should provide correct information on science and that the environment is fun and interesting for participants (Dmoshinskaia et al., 2022). Apart from these characteristics, multiple more specific characteristics are defined explicitly for outreach programs such as museum lessons. These characteristics are stated as follows:

- The activity shows a clear connection with science in everyday life.
- The activity topic contributes to science proficiency development and complements existing learning activities in formal situations.
- The activity connects to the personal interests and experiences of participants.
- The activity stimulates a curious and critical attitude while studying phenomena.
- The activity stimulates participation by using hands-on activities and interaction.
- The activity allows for collaboration with peers.
- The activity takes age and ability into account. (Dmoshinskaia et al., 2022)

These characteristics correspond substantially with the design characteristics named by the NRC (2015) that informal learning should be engaging, responsive and make connections. The internal and external characteristics of informal STEM learning defined in the first paragraph can be recognised herein.

It is not yet known if there is a difference in importance among these characteristics. It could be interesting for informal learning environments to know which characteristics need to be emphasised the most. Therefore, this study investigates the characteristics that are mentioned the most by fifth- and sixth-grade students concerning their experience in the museum to see what characteristics institutions should focus on in their environments.

Research questions

The theoretical framework showed the definitions of informal STEM learning and its characteristics, prior knowledge and the processes of content knowledge and scientific reasoning separately in the context of informal STEM learning. The following research questions are formulated to look at the relationship between these variables:

1. To what extent does engaging with an informal STEM learning environment influence the gaining of content knowledge and scientific reasoning ability by fifth and sixth-grade primary school students?

2. What is the effect of prior knowledge on the gaining of content knowledge and ability of scientific reasoning in an informal STEM learning environment by fifth and sixth-grade primary school students?
3. Which design characteristics contribute the most to the gaining of content knowledge and ability of scientific reasoning, according to the participants?

Scientific & practical relevance

Not much research has been done regarding the effects of prior knowledge on the development of children's content knowledge and scientific reasoning. Previous research has focused on the impact of informal STEM learning on content knowledge and scientific reasoning (e.g., NRC, 2015) and on the effect of prior knowledge on engaging with informal learning environments (e.g., Simonsmeier et al., 2021). Still, the combination of these factors is much less studied. By conducting this study, more will be known about this combination of effects.

Moreover, this study will add to the knowledge base of the project Surrounded by Science. The outcomes of this study will be considered when the project designs its ecosystem of collaboration between formal and informal institutions. Finally, this research will provide insights for the Museumfabriek on what educational effects their museum lessons have and what characteristics contribute the most to these effects, which can be helpful for future adjustments or new lessons in the Museumfabriek.

Method

Research design

A mixed-method approach is used to study the effects of prior knowledge and design characteristics on content knowledge and scientific reasoning. The quasi-experimental research design includes seven experimental groups divided over two different museum lessons, with 127 participants in total. The quantitative part of the study contains a pre- and post-test, used to study differences in concept knowledge and scientific reasoning and to give insights into the participants' prior knowledge.

The qualitative part of the study consists of a short focus-group interview to gain an understanding of the design characteristics that contributed the most to the participants' gaining of knowledge and scientific reasoning skills.

Respondents

The study includes 127 participants, targeted out of a research population that includes primary school students from fifth or sixth grade visiting the informal learning environment Museumfabriek. The participants are divided into seven groups of fifth- or sixth-grade in three primary schools in the Netherlands. These participants are selected using convenience sampling: the participants are pre-divided into school classes that have already booked a museum lesson at the Museumfabriek. For the interview, three students per class are randomly selected to express their ideas about the museum lesson in a focus group.

When parents declined permission for their child to participate in the study, the data from this child is not included in the analysis.

Materials

Museum lesson

The intervention consists of a museum lesson in the Museumfabriek. Seven groups of participants are divided over two museum lessons: a biology lesson called “Tricks from nature: Form and Function” (Dutch: “Trucs van de natuur: Vorm en Functie”) and a history lesson called “Timemachine Twente: from Mammoth to Steam Engine” (Dutch: “Tijdmachine Twente: van Mammoet tot Stoommachine”). History itself is not part of STEM, but this lesson includes some STEM elements, like focusing on technological revolutions (the use of tools, the development of the loom) and using research elements (Museumfabriek, personal communication, January 27, 2023) and is therefore suitable to study in this regard. Both museum lessons take 90 minutes, are designed for groups of fifth- or sixth-graders of primary school, and are guided by a museum teacher (Museumfabriek, 2023).

The biology museum lesson “Tricks from nature: Form and Function” consists of two parts. In the first part, the participants are guided through the museum, where they look at models of animals and their habitats and lifestyles. In the second part, the participants design a model of an animal and its habitat.

The history museum lesson “Timemachine Twente: from Mammoth to Steam

Engine" also consists of two parts. In the first part, the participants immerse themselves in the lifestyle of the inhabitants of Twente through the ages using school posters. In the second part, the participants are guided through the museum and see a demonstration of a loom.

Pre- and post-test

To determine content knowledge and scientific reasoning, both a pre- and a post-test are conducted. Parallel testing is used: the test differs for both museum lessons, and the post-test differs from the pre-test but is still comparable.

The tests for the biology lessons consist of eight items each and are constructed using learning outcomes from the Museumfabriek (personal communication, January 27, 2023). Content knowledge was assessed with four items. The items are constructed based on the learning goal of the Museumfabriek for this lesson, which is for the participants to understand the connection between the external characteristics of animals and their respective habitats, nutrition, and enemies. An example item is: "Underneath, you can find a couple of animals. They live together in the same area. What area is this? Draw this area around the animals" (item 2a). Scientific reasoning was also assessed with four items, for example: "Why do the animals fit in the area that you have drawn?" (Item 2b). The pre- and post-tests of these questions differ in what animals they show. The full pre- and post-test in Dutch can be found in Appendix A and B, respectively.

The tests for the history lessons also consist of eight items each and are again constructed using the learning outcomes of the Museumfabriek (personal communication, January 27, 2023). Content knowledge was assessed with four items. The items are constructed based on the learning goal of the Museumfabriek for this lesson, which is for the participants to understand the historical context of human habitation in their local area and to recognise the everyday needs that have persisted over time and the tools that were needed to fulfil these needs. An example item is: "Make a drawing that fits in the time of hunters and gatherers." (Item 6a). Scientific reasoning was assessed with four items, for example: "Why does your drawing fit in the time of hunters and gatherers?" (Item 6b). For these questions, the pre- and post-test differ in the era of time that is asked: the post-test asks for a drawing of the time of the factories. The full pre- and post-test in Dutch can be found in Appendix C and D.

The total score for the biology tests ranges from 0-36, where the total score for content knowledge ranges from 0-12 and for scientific reasoning ranges from 0-24. The total score for the history tests ranges from 0-39, where the total score for content knowledge ranges from 0-13 and for scientific reasoning ranges from 0-26. Points are given according to the coding scheme that can be found in Appendix E. The students score one point for every right component in the content knowledge questions. The students score two points for every right component in the scientific reasoning questions since reasoning is a higher-order skill than remembering according to Bloom's revised taxonomy (Anderson et al., 2000) and, therefore, more difficult to answer. The points are measured as ratio variables.

To measure the influence of prior knowledge, the participants that scored more than half of the points for content knowledge are marked as having prior knowledge. The participants are split into two groups: a group with prior knowledge and a group without prior knowledge. The difference between the pre- and post-test is separately measured for these groups to see the difference between having and not having prior knowledge.

The tests are pilot tested with 22 students in grade 5. The participants of the pilot test are asked to fill in the tests and evaluate them by indicating which parts they did not fully comprehend to ensure face validity. The tests are also shown to an expert to ensure face validity.

The reliability of the tests is measured with Cronbach's α. The biology tests have an overall α of .76, with an α of .62 for the pre-test and an α of .65 for the post-test. These α scores indicate moderately acceptable reliability for these tests. The history tests have an overall α of .73, indicating acceptable reliability. However, separating the pre- and post-test gives the reliability of respectively .38 and .62, which are poor and moderately acceptable. The poor reliability of the pre-test can be explained by the fact that most of the participants did not know about the topic beforehand, which resulted in many unanswered questions that did not give enough information to calculate the reliability of the tests correctly. Nonetheless, the results of these history tests, particularly the pre-test, should be interpreted with caution.

Interview

To determine the design characteristics that contribute to the learning gains in concept knowledge and scientific reasoning, a short semi-structured interview is used to find out about the participants’ views. The interview consists of five items and can be found in Appendix F. An example of an interview item is “What did you think was the most educational part of the trip?”. The interview questions are piloted with 22 students from grade 5, and an expert has looked at the questions to ensure validity. The interviews are recorded, transcribed, and coded using a coding scheme.

Procedure

To reach the participants of this research, the teachers are contacted for permission to conduct this research with their students. Since the participants are underage, their parents are informed about the study and asked to consent to research with their children. Before the participants were contacted, the study was reviewed by the BMS Ethics Committee to ensure the ethical responsibility of the study. The students and teachers from the classes and the instructors who provide the museum lessons are involved in the study.

The data collection took approximately ten days per class and consisted of pre-testing, visiting the museum, participating in an interview and post-testing. Per group, the participants took a 20-minute pre-test to measure their current scientific reasoning and content knowledge. This test took place in the school. The outcomes of this pre-test determined the prior knowledge of the participants. A week after the pre-test, the participants visited the Museumfabriek and followed a 90-minute program. Directly after the program, a group of three students was interviewed in a 15-minute interview about the design characteristics of the trip. Around three days after the visit, the group took a 20-minute post-test in school to measure the difference in scientific reasoning and content knowledge before and after the program in the Museumfabriek. A summary of the outcomes of this study is communicated with the schools and Museumfabriek. In this summary, the results are anonymised.

Data analysis

The data from the tests is pseudonymised by connecting the names of the participants to a number to compare the pre- and post-test. No other personal data was gathered. The participants' prior knowledge is used as an independent variable, while the potential gains in content knowledge and scientific reasoning ability are used as a dependent variable.

To select a proper test to analyse the data, a Shapiro-Wilk test was conducted to determine whether the results were normally distributed.

For the biology tests, the Shapiro-Wilk test showed that the differences in the whole test ($W(52) = .89$, $p < .001$) as well as in the content knowledge part ($W(52) = .92$, $p = .002$) and the scientific reasoning part ($W(52) = .90$, $p < .001$) are significantly different from a normal distribution (< α .05). This test and its separate parts cannot be assumed to be normally distributed. Therefore, the Wilcoxon Rank Sum test will be used to analyse the data for these tests.

For the history tests, the Shapiro-Wilk test showed that the differences in the whole test ($W(53) = .98$, $p = .338$) and in the content knowledge part ($W(53) = .97$, $p = .143$) are not significantly different from a normal distribution (> α .05) and therefore can be assumed to be normally distributed. For the scientific reasoning part, the Shapiro-Wilk test showed a significant difference from a normal distribution ($W(53) = .93$, $p = .005$) (< α .05). This part of the test cannot be assumed to be normally distributed. Therefore, to analyse this data, for the whole test and the knowledge part, an independent t-test will be used. For the scientific reasoning part, a Wilcoxon Rank Sum test will be used.

The data from the interviews was anonymised by giving the respondents numbers. No other personal data was gathered. The interviews are recorded, transcribed, and coded. The interviews are coded with a coding scheme which can be found in Table 1, which includes the characteristic, description, and an example of each code. The coding scheme is developed using the design characteristics as formulated by the Surrounded by Science project.

In Table 1, “characteristic” stands for the design characteristic as stated by the Surrounded by Science project, with “description” as the description given by the project (Dmoshinskaia et al., 2022). The interview utterances are coded as utterances about a specific design characteristic. An example of such an utterance per characteristic can be found in Table 1 under “example”.

Table 1

Rubric for the classification of utterances from the interview transcripts

Characteristic	Description	Example
Being interesting and fun	Remarks towards the inclusion or absence of fun and interesting elements.[1]	"I liked it this time. Normally I do not like history."
Delivery of correct science information	Remarks towards the inclusion or absence of correct information about scientific topics.	*No remarks*
Connection to real-life science	Remarks towards the inclusion or absence of a connection between the presentation of the activity and the science behind it in real-life situations.	"I thought the loom was very educational because I have a small loom at home."
Choice of a relevant topic	Remarks towards the inclusion or absence of a choice of a topic that contributes to science proficiency development and complements the in-school activities.	"No, I already knew everything, and I did not like going there. I would rather just learn mathematics or language."
Stimulation of a curious and critical attitude	Remarks towards the inclusion or absence of stimulation of curiosity and a critical attitude towards the shown phenomena and the studying of these phenomena in the activity.	"I liked it because we learned things we did not know before."
Contribution to personal interests and experiences	Remarks towards the inclusion or absence of a connection between the activity and the personal interests of the participants and a contribution of the activity to the participants' personal experiences.	"The animals were just cute. I saw the fox, and he was so cute, I started talking to him spontaneously!"
Hands-on activities and	Remarks towards the inclusion or	"I liked it better the last

interaction	absence of active participation and hands-on activities in the activity.	time I went with my mom. That time we actually made things.”
Peer collaboration	Remarks towards the inclusion or absence of the possibility to collaborate with peers in the activity.	“The best thing was the glueing and that we could study an animal ourselves because we could do these things in a team.”
Age- and ability-appropriateness	Remarks towards the inclusion or absence of the use of language and tasks on the level of the participants.	*No remarks*

[1]*Since the questions were specifically about what elements were fun or interesting/educational, the utterances counted were those outside these questions or when it is part of the reasoning.*

Results

In the following sections, the data from the tests, as well as the interviews, is analysed.

Descriptive statistics

Before the museum visit, 61 participants completed the biology pre-test. After the museum visit, 59 participants completed the biology post-test, including some participants who did not fill in the pre-test. Some of the data had to be excluded. In total, the data of 52 participants are included in the analysis. The tests included both content knowledge questions and scientific reasoning questions. Table 2 shows the number of respondents (N), minimum (MIN), maximum (MAX), mean (M) and standard deviation (SD) values of the biology pre-test, post-test and the difference between the scores for these tests. The difference between the tests was calculated by subtracting the pre-test score from the post-test score. The scores for the specific content knowledge questions (K) and scientific reasoning questions (R) are separately mentioned.

Table 2

Descriptive statistics biology tests

	N	MIN	MAX	M	SD
Total pre-test	54	0.0	21.0	10.51	4.66
Total pre-test K	54	0.0	12.0	8.07	2.95
Total pre-test R	54	0.0	10.0	2.44	2.44
Total post-test	54	5.0	27.0	13.36	4.33
Total post-test K	54	4.0	12.0	9.62	1.77
Total post-test R	54	0.0	16.0	3.74	3.27
Total difference	52	-6.0	24.0	2.87	4.85
Total difference K	52	-4.0	10.5	1.48	3.04
Total difference R	52	-4.0	14.0	1.39	3.14

Prior to the museum visit, 59 participants completed the history pre-test. After the museum visit, 57 participants completed the history post-test, including some participants who did not fill in the pre-test. In total, 53 participants completed both tests, and these participants are included in the analysis. The tests included both content knowledge questions and scientific reasoning questions. Table 3 again shows the number of respondents (N), minimum (MIN), maximum (MAX), mean (M) and standard deviation (SD) values of the history pre-test, post-test, and the difference between the scores for these tests. The difference between the tests was calculated by subtracting the pre-test score from the post-test score. The scores for the specific content knowledge questions (K) and scientific reasoning questions (R) are separately mentioned.

Table 3

Descriptive statistics history tests

	N	MIN	MAX	M	SD
Total pre-test	59	1.0	18.5	7.559	3.9850
Total pre-test K	59	1.0	10.0	5.186	2.2243
Total pre-test R	59	0.0	11.0	2.373	2.6855
Total post-test	57	2.0	28.0	14.412	6.4939
Total post-test K	57	2.0	11.0	7.588	2.0247
Total post-test R	57	0.0	20.0	7.000	5.5453
Total difference	53	-3.0	16.0	6.6981	4.85099
Total difference K	53	-3.0	7.0	2.4528	2.46175
Total difference R	53	-2.0	15.0	4.4340	4.37985

Question 1: gaining of content knowledge and scientific reasoning

In this part of the analysis, the following research question is investigated:

To what extent does engaging with an informal STEM learning environment influence the gaining of content knowledge and scientific reasoning ability by fifth and sixth-grade primary school students?

To answer this question, a one-sample t-test with α = .05 was used to study whether there is enough evidence to conclude a significant difference between the pre-test and the post-test results. A Wilcoxon Signed Rank test was used explicitly for the history part about scientific reasoning since the data is not normally distributed enough. For the biology tests, the complete tests and the content knowledge and scientific reasoning part of the test, the Wilcoxon Signed Rank test was again used since the data is not normally distributed enough.

For the biology part, the one-sample Wilcoxon Signed Rank test showed a significant difference for the differences in the complete test (*Mdn.* = 2.0): z = -4.12, p < .001, the content knowledge part of the test (*Mdn.* = 1.0): z = -3.12, p = .002, and the scientific reasoning part of the test (*Mdn.* = 2.0): z = -2.96, p = .003.

For the history part, the one-sample t-test showed a significant difference for both the differences in the complete test (M = 6.70, SD = 4.85): $t(52)$ = 10.05, p < .001, and the content knowledge part of the test (M = 2.45, SD = 2.46): $t(52)$ = 7.25, p < .001. The one-sample Wilcoxon Signed Rank test for the difference between scientific reasoning parts of the tests also showed a significant difference (*Mdn.* = 4.00): z = -5.37, p < .001.

Question 2: influence of prior knowledge

In the next part of the analysis, the following research question is investigated:

What is the effect of prior knowledge on the potential gaining of content knowledge and ability of scientific reasoning in an informal STEM learning environment by fifth and sixth-grade primary school students?

To answer this question, a two-sample t-test with α = .05 or a Wilcoxon Rank Sum test was used to study whether there is enough evidence to conclude that there is a significant difference between students with prior knowledge and students without prior knowledge in their differences between the pre-test and the post-test. For the history part, the whole test was tested with a pooled t-test since equal variances could not be assumed (Levene's test = .01, *p* = .934). The content knowledge part was tested with a general t-test since equal variances can be assumed (Levene's test = 8.99, *p* = .004). A Wilcoxon Rank Sum test was used for the scientific reasoning part of the test since the data is not normally distributed enough.

The whole biology test was tested with a Wilcoxon Rank Sum test for the biology tests since the data is not normally distributed enough.

For the biology tests, the Wilcoxon Rank Sum test showed for the overall test that there is enough evidence to conclude that there is a significant difference between students with (*Mdn.* = 2.0) and without prior knowledge (*Mdn.* = 7.00): *z* = -4.05, *p* < .001. For the content knowledge part, the Wilcoxon Rank Sum test again showed that there is enough evidence to conclude that there is a significant difference between students with (*Mdn.* = .50) and without prior knowledge (*Mdn.* = 5.00): *z* = -4.99, *p* < .001. For the scientific reasoning part, however, the Wilcoxon Rank Sum test showed that there is not enough evidence to conclude that there is a significant difference between students with (*Mdn.* = 2.00) and without prior knowledge (*Mdn.* = 2.00): *z* = -.59, *p* = .555.

For the history tests, the two-sample t-test showed for the overall test that there is not enough evidence to conclude that there is a significant difference between students with (*M* = 7.32, *SD* = 4.97) and without prior knowledge (*M* = 6.47, *SD* = 4.85): *t*(22.5) = -.550, *p* = .588. For only the content knowledge part, however, the two-sample t-test showed that there is enough evidence to conclude that there is a significant difference between students with (*M* = .64, *SD* = .91) and without prior knowledge (*M* = 3.10, *SD* = 2.52): *t*(51) = 3.55, *p* = .001. The Wilcoxon Rank Sum test for the scientific reasoning part showed that there is enough evidence to conclude that there is a significant difference between students with (*Mdn*. = 8.00) and without (*Mdn.* = 2.00) prior knowledge: *z* = -2.501, *p* = .012.

Question 3: contribution of design characteristics

In the qualitative part of the analysis, the following research question is investigated:

Which design characteristics contribute the most to the potential gaining of content knowledge and ability of scientific reasoning, according to the participants?

The goal of the interviews studied was to identify the design characteristics of the informal learning environment that, according to the students, contribute the most to their learning experience. Based on the coding scheme in Table 1, the interviews were analysed. The number of participants that addressed a design characteristic can be found in Table 4.

Table 4

Frequency of utterances per design characteristic

Characteristic	N	%
The activity was fun and interesting to participate in.	18	85.7
The activity delivered correct information about the scientific topics.	0	0
The activity shows a clear connection with science in everyday life.	1	4.8
The activity topic contributes to science proficiency development and complements existing learning activities in formal situations.	6	28.6
The activity connects to the personal interests and experiences of participants.	14	66.7
The activity stimulates a curious and critical attitude while studying phenomena.	18	85.7
The activity stimulates participation by using hands-on activities and interaction.	17	81.0
The activity allows for collaboration with peers.	3	14.3
The activity takes age and ability into account.	0	0
Total	21	100

In the following paragraph, information about the content of the utterances will be stated for the five design characteristics mentioned the most.

The activity was fun and interesting to participate in.

The remarks around this characteristic were specifically made around the familiarity of the information: participants for whom the information was new found the visit fun and informative, whereas participants for whom the information was already known found the visit less fun and sometimes dull.

The activity stimulates a curious and critical attitude while studying phenomena.

This characteristic was most mentioned during the questions about the most educational part of the trip or what was missed. The museum lessons did not cover all the museum exhibits, and many participants stated that they wanted to see more of the museum and learn more about what could be found there.

The activity stimulates participation by using hands-on activities and interaction.

The possibility of doing hands-on activities was mentioned both in the context of the most engaging as well as the most educational parts of the visit. The history lesson included fewer hands-on activities than the biology lesson, and the participants that followed the history lesson mentioned that they wanted to do more activities. The participants that took the biology lesson were happy with the number of hands-on activities or would have liked a more balanced combination of information and activities since their activity took quite some time.

The activity connects to the personal interests and experiences of participants.

This design characteristic appeared to be one of the most essential factors for engagement for many participants. When asked what they liked the most about the visit, most participants from both the biology lesson and the history lesson mentioned items in the museum that were ‘nice’, ‘cool’ or ‘cute’. This showed that the museum involved a lot of interesting and exciting materials to learn about or work with and an emotional connection between the participants and the items. This characteristic was not mentioned by participants as something they missed or would have liked more.

The activity topic contributes to science proficiency development and complements existing learning activities in formal situations.

This design characteristic appeared to be the main reason participants did *not* like the visit. The participants said they did not like the visit because they already knew a lot about what was taught because they learned about it in school. However, the participants who liked the visit said they liked the part where they learned new things. This was the case for both the history lesson and the biology lesson.

Discussion

In this chapter, the results from the previous chapter will be explained and put into perspective. Additionally, the implications of these conclusions, the limitations of this study, and recommendations for further research are stated.

Conclusions

Question 1: gaining of content knowledge and scientific reasoning

The first research question about gaining content knowledge and scientific reasoning was investigated by analysing the pre- and post-tests. This analysis showed that the post-test results were significantly higher for all the tests and subcategories than those from the pre-tests. This aligns with previous studies stating that hands-on learning experiences that allow for collaboration, authentic experiences and inquiry-based learning with all its different steps contribute to the gaining of content knowledge and scientific reasoning (Fischer et al., 2014; Khanaposhtani et al., 2018; NRC, 2009; NRC, 2015; Norris et al., 2014; Opiz et al., 2017; Pedaste et al., 2015). Both museum lessons included these characteristics, which could explain the significant gaining of the participants' content knowledge and scientific reasoning.

Question 2: influence of prior knowledge

The second research question about the effect of prior knowledge on content knowledge and scientific reasoning gains was investigated by analysing the pre- and post-tests for subgroups with and without prior knowledge. This analysis showed some differences between tests and categories.

The analysis of the biology test showed that the results for the complete pre- and post-test and the content knowledge parts were significantly different. Both groups scored higher on the post-test than on the pre-test. However, the score difference for the group without prior knowledge was more substantial than for the group with prior knowledge. For the scientific reasoning part, no differences between the groups were found. The analysis of the history test did not find differences between the groups on the whole test. However, for the content knowledge part, the score difference for the group with prior knowledge was more substantial than for the group without prior knowledge. For the scientific reasoning part, it was the other way around.

These results, except for the results for content knowledge for the history test, do not align with the previous studies stating that prior knowledge is a strong predictor for developing knowledge about STEM (Dochy et al., 1999; Khanaposhtani, 2018; Shapiro, 2004), specifically in informal learning environments (Falk & Dierking, 2000, as cited in Falk & Adelman, 2003). Since no participant scored the maximum score, this cannot be explained by a lack of opportunity to show knowledge or reasoning. There are multiple factors that could explain this difference.

First, Simonsmeier et al. (2021) highlighted that several previous studies mainly focused on learning outcomes in general and not on the learning gains, the differences between content knowledge and scientific reasoning before and after engaging with the informal learning environment. It is still possible that the groups with prior knowledge scored higher on the post-test than the groups without prior knowledge, yet the comparison with the pre-test shows a smaller growth.

Another explanation can be found in the interviews, where the participants who knew more about the presented topic complained that the trip was 'boring'. In contrast, the participants who were enthusiastic about the trip said this was, among other things, because they learned 'so many new things'. The NRC (2009, 2015) and the Surrounded by Science project (Dmoshinskaia et al., 2022) mentioned 'being fun and interesting' as one of the design characteristics that are prerequisites for an environment to be a learning environment. The comments about the trip being less fun because the participants already knew much of what had been told could indicate that these participants had prior knowledge on the tests. In this case, the fact that this design characteristic was lacking specifically for participants with prior knowledge could explain the lower difference for this group in gaining content knowledge and scientific reasoning.

Question 3: contribution of design characteristics

The last research question about the level of contribution of the design characteristics to the content knowledge and scientific reasoning gains was investigated by analysing the focus-group interviews. Looking at the interviews, the design characteristics as mentioned by the Surrounded by Science project (Dmoshinskaia et al., 2022) could be equally divided into more and less mentioned characteristics. The more mentioned characteristics are:

1. The activity was fun and interesting to participate in;
2. The activity stimulates a curious and critical attitude while studying phenomena;
3. The activity stimulates participation by using hands-on activities and interaction;
4. The activity connects to the personal interests and experiences of participants;

5. The activity topic contributes to science proficiency development and complements existing learning activities in formal situations.

The less-mentioned characteristics are:

6. The activity allows for collaboration with peers;
7. The activity shows a clear connection with science in everyday life;
8. The activity delivered correct information about the scientific topics;
9. The activity takes age and ability into account.

The characteristics on the higher end of the ranking could explain some of the outcomes of the pre- and post-test. As stated in the previous paragraph, the fact that the group with prior knowledge showed less learning and reasoning gains compared to the group without prior knowledge could be explained by the fact that complementing existing formal learning activities is an important characteristic, as well as being fun and interesting and stimulating a curious and critical attitude. Since the participants explained in the interviews that some parts were boring and did not include new, exciting, complementary information outside of the formal information because they already had prior knowledge, this could explain the lesser growth in knowledge and reasoning.

Some characteristics on the lower end of the ranking are not mentioned at all, namely the delivery of correct information and the compliance with the age and ability of the participants. A possible explanation for this is that participants of this age group take this for granted and expect an informal environment to deliver correct information for their age group and do not feel the need to make explicit statements about this.

It should be noted that the design characteristics analysed here are derived from the characteristics of outreach programs. Whilst the activities described in this study are indeed outreach programs, some parts correspond to the description of a guided tour as well, which is part of the activity type “designed environments”. This type includes some extra or different characteristics which are not considered in this study and, therefore, cannot be said anything about concerning the perspective of the participants. However, they might be interesting to investigate.

Further research could study the reason behind the differences in the number of utterances about the design characteristics in more detail.

Implications

This study adds to the knowledge base of the project Surrounded by Science, which can help with the design of the ecosystem for formal and informal learning environments. Moreover, this study can give insights to schools into what effects visiting an informal learning environment has on children's content knowledge and scientific reasoning and what characteristics of these environments need to be considered when deciding which environment will be visited. Finally, this research sheds light for the Museumfabriek on what educational effects their museum lessons have. It shows what characteristics are found meaningful by the participants, which can be considered by designing new lessons or exhibitions.

Limitations

This research has some limitations. First, the participants are selected using convenience sampling, and the sample is therefore not random. Apart from that, the sample consisting of 127 participants is relatively small. These facts could mean that the sample does not fully represent the entire population. Another limitation is that one test has poor reliability, meaning the results should be interpreted cautiously. Finally, other factors could potentially affect the outcomes that are not accounted for, for example, the preparation and evaluation in class before and after the trip. Such a preparation or evaluation can affect how much students remember and how students reason, apart from the informal learning environment.

Future directions

Future researchers are encouraged to perform a more detailed study on the effects of prior knowledge on children's content knowledge and scientific reasoning competencies and the mechanisms behind this difference. A more extended and detailed study could increase the representation by studying more participants. It could also account for other variables that could affect the outcomes. Lastly, it could look at the reasons that cause the students with more prior knowledge to have less learning and reasoning gains than students without prior knowledge. Furthermore, future researchers are encouraged to investigate the reasons behind the differences in mentions of the design characteristics to investigate why students from fifth and sixth grade mention some characteristics more than others.

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Appendices

A: Pre-test Biology Tricks from nature: Form and Function

1. Hieronder staan drie soorten wolven. Elke wolf leeft in een ander soort gebied.
   a. Verbind de wolf met het juiste gebied.

1. 
   • • Noordpool

2. 
   • • Nederland

3. 
   • • Woestijn

b. Waaraan kun je dat zien?

- ○ Ik heb gegokt
- ○ Door:

____

____

____

____

Hieronder staan drie soorten vogels. Elke vogel eet iets anders.

a. Verbind de vogel met het juiste eten.

1

2

3

Insecten en bessen | kleine landdieren | kleine waterdieren

b. Waaraan kun je dat zien?

○ Ik heb gegokt
○ Door:

____

____

____

____

2. Hieronder staan een paar dieren. Ze leven samen in hetzelfde gebied.
a. In wat voor gebied leven ze? Teken dat gebied om de dieren heen.



b. Waarom passen de dieren in het gebied dat je hebt getekend?

3. a. Teken nu zelf een dier! Het moet een **vogel** zijn die bij het **water** leeft en **kleine visjes** eet. Je mag zelf weten of je een bestaand dier of een fantasiedier tekent.

b. Waaraan zie je dat dit een waterdier is die kleine visjes eet? Zet daar **pijltjes** bij.

B: Post-test Biology Tricks from nature: Form and Function

1. Hieronder staan drie soorten vossen. Elke vos leeft in een ander soort gebied.
b. Verbind de vos met het juiste gebied.

1.  •   • Noordpool

2.  •   • Nederland

3.  •   • Woestijn

b. Waaraan kun je dat zien?

○ Ik heb gegokt
○ Door:

____

____

____

____

2. Hieronder staan drie soorten vogels. Elke vogel eet iets anders.
a. Verbind de vogel met het juiste eten.



insecten en bessen   kleine landdieren   kleine waterdieren

b. Waaraan kun je dat zien?

- ○ Ik heb gegokt
- ○ Door:

____

____

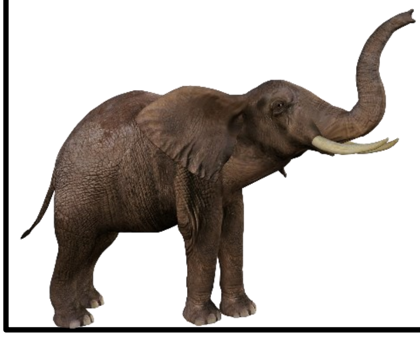
____

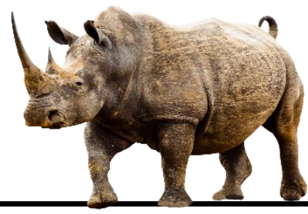
____

____

3. Hieronder staan een paar dieren. Ze leven samen in hetzelfde gebied.

a. In wat voor gebied leven ze? Teken dat gebied om de dieren heen.





c. Waarom passen de dieren in het gebied dat je hebt getekend?

____

____

____

____

4. a. Teken nu zelf een dier! Het moet een **roofdier** zijn die in een heel **koud** gebied woont. Je mag zelf weten of je een bestaand dier of een fantasiedier tekent.

b. Waaraan zie je dat dit een roofdier in een koud gebied is? Zet daar **pijltjes** bij.

C: Pre-test History Timemachine Twente: from Mammoth to Steam Engine

1) Zet de tijden in de goede volgorde van vroeger naar nu:

onze tijd – iedereen boer – jagers en verzamelaars – tijd van de fabrieken – de eerste boeren

1. ____
2. ____
3. ____
4. ____
5. ____

2) In de tijd van de *eerste boeren* **stopten de mensen met rondreizen en bleven de mensen op een vaste plek. Waarom?**

____

____

____

____

3) Dit is Johannes. Johannes vertelt wat over zijn leven:

"Ik heb slecht geslapen vannacht. Ik dacht dat ik buiten een heks hoorde. Dat komt vast omdat mijn kleindochter een eng heksenverhaal heeft verteld. Gelukkig begon de dag goed. Mijn vrouw en schoondochter hebben genoeg draad gesponnen om nieuwe kleding te maken. Mijn zoon gaat er vanmiddag op het weefgetouw in de boerderij mee beginnen. Ik zie dat de koffie op is. Dat moeten we straks halen als de marskramer langs komt.

Kijk naar de tijden bij vraag 1.

a) **In welke tijd leefde Johannes? De tijd van**

   ____

b) **Zet een streep onder de stukken in de tekst waardoor je dit wist.**
   (Als je hebt gegokt, zet dan geen strepen).

4) Kleur *drie* woorden in die het beste passen bij de *tijd van de fabrieken.*

heksenverhalen

internet

steden groeien heel snel

hele groepen mensen en dieren in één huis

televisie

geen vaste woonplaats

ijstijd

stoommachine

vuursteen

eerste vaste woningen

telefoons

weven in de fabriek

marskramer

weven op de boerderij

5) Waarom werd de tijd van de *eerste boeren* **ook wel de** *ijzertijd* **genoemd?**

____

____

____

____

6) a. Maak een tekening die past bij de tijd van *jagers en verzamelaars.*

b. Waarom past jouw tekening bij de tijd van *jagers en verzamelaars***?**

____

____

____

____

D: Post-test History Timemachine Twente: from Mammoth to Steam Engine

1) Zet de tijden in de goede volgorde van vroeger naar nu:

onze tijd – iedereen boer – jagers en verzamelaars – tijd van de fabrieken – de eerste boeren

1. ______________________________________
2. ______________________________________
3. ______________________________________
4. ______________________________________
5. ______________________________________

2) In de tijd van de fabrieken groeiden steden zoals Enschede heel snel.

Waardoor kwam dat?

____

____

____

____

3) Dit is Ayla. Ayla vertelt wat over haar leven:

"Gisteren zijn we naar een nieuw gebied gereisd omdat er geen eten meer was in het oude gebied. Morgen gaan mijn vader en mijn oom samen met de andere mannen op zoek naar dieren. Ze nemen vuurstenen mee, die kunnen ze goed gebruiken. Ik ga met mijn moeder naar het bos om bessen te zoeken. Ik hoop dat we hier wel eten vinden, anders gaan we weer verder reizen."

Kijk naar de tijden bij vraag 1.

c) In welke tijd leefde Ayla? De tijd van ______________________________

d) Zet een streep onder de stukken in de tekst waardoor je dit wist.
(Als je hebt gegokt, zet dan geen strepen).

4) Kleur *drie* woorden in die het beste passen bij de tijd: *iedereen boer*

heksenverhalen internet televisie

allerlei gezinnen en dieren in één huis

vuursteen

geen vaste woonplaats

stoommachine

ijstijd

eerste vaste woningen

telefoons

weven in de fabriek

marskramer

weven op de boerderij

5) Waarom werd de tijd van *jagers en verzamelaars* **soms ook** *steentijd* **genoemd?**

____

____

____

____

6) a. Maak een tekening die past bij de *tijd van de fabrieken.*

b. Waarom past jouw tekening bij de *tijd van de fabrieken*?

____

____

____

____

E: Coding scheme tests

Tricks of Nature: Form and Function pre-test

Question	Knowledge (K)/ reasoning (R)	Points per	Max.
1a	K	1 point per correct line	3
1b	R	2 points per - Fur - Colour - Ears	6
2a	K	1 point per correct line	3
2b	R	2 points per - Beak - Legs/claws - neck	6
3a	K	3 points for clear cold/snowy surroundings	3
3b	R	2 points per - fur - colour - ears	6
4a	K	1 point per characteristic: - long and/or flat beak - flippers OR long legs/neck - feathers	3
4b	R	2 points per arrow to - beak - flippers OR long legs/neck - feathers	6

Total Knowledge: 12

Total Reasoning: 24

Tricks of Nature: Form and Function post-test

Question	Knowledge (K)/ reasoning (R)	Points per	Max.
1a	K	1 point per correct line	3
1b	R	2 points per - Fur - Colour - Ears	6
2a	K	1 point per correct line	3
2b	R	2 points per - Beak - Legs/claws - neck	6
3a	K	2 points for clear warm surroundings 1 point for an open field (not densely wooded)	3
3b	R	2 points per - big animals - no fur - protruding parts	6
4a	K	1 point per characteristic - white fur OR thick fur and very big - small ears - strong teeth and/or claws	3
4b	R	2 points per arrow to - white fur OR thick fur and very big - small ears - strong teeth and/or claws	6

Total Knowledge: 12

Total Reasoning: 24

Time machine Twente: from Mammoth to Steam engine pre-test

Question	Knowledge (K)/ Reasoning (R)	Points per	Max.
1	K	1 point per correctly placed period	5
2	R	2 points per line of reasoning: - became farmers - waiting for crops - no need to travel when there is no food	6
3a	K	1 point for the correct period	1
3b	R	2 points per correct line	8
4	K	1 point per correct word	3
5	R	2 points per line of reasoning - people started to use iron - to make tools - instead of stone as before	6
6a	K	1 point per component: - stone tools - hunting people - gathering people - ice surroundings	4
6b	R	2 points per explained component	6

Total Knowledge: 13

Total Reasoning: 26

Time machine Twente: from Mammoth to Steam engine post-test

Question	Knowledge (K)/ Reasoning (R)	Points per	Max.
1	K	1 point per correctly placed period	5
2a	K	1 point for the correct period	1
2b	R	2 points per correct line	8
3	R	2 points per line of reasoning: - people moved to the city - because factories grew - because farmers wanted to work in factories	6
4	K	1 point per correct word	3
5	R	2 points per line of reasoning - people used (fire)stone - to make tools - because there was no metal yet	6
6a	K	1 point per component: - factories - steam engine - big city - weaving in the factory	4
6b	R	2 points per explained component	6

Total Knowledge: 13

Total Reasoning: 26

F: Interview questions

Dutch:

1. Wat vond je van het museumbezoek? Waarom?
2. Welk onderdeel vond je het leukst van het bezoek? Waarom?
3. Welk onderdeel vond je het meest leerzaam van het bezoek? Waarom?
4. Wat vond je van de gids? Waarom?
    a. Maakte hij/zij je enthousiast?
    b. Kon hij/zij goed uitleggen?
5. Denk je dat het museum iets beter kon doen? Wat? Waarom?

English:

1. What did you think of the museum visit? Why?
2. What part of the trip did you like most? Why?
3. What did you think was the most educational part of the trip? Why?
4. What did you think of the guide? Why?
    a. Did they engage you?
    b. Could they explain well?
5. Did you think the museum could do something better? What? Why?