Learning science in interactive exhibitions.

Frameworks for design and evaluation of material for exploratory learning experiences.

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Abstract

This study addresses utilization of interactive science exhibitions as resources that support students' progress towards conceptual understanding of science. Informed by previous empirical studies related to our area of research, we conduct a review, presented in the current study, titled "*Exhibitions as learning environments: a review of empirical research on students' science learning at Natural History Museums, Science Museums and Science Centres*" (Hauan & Kolstø, 2014). By the review, we identified two research areas which inspired the two other studies in this thesis: 1) Exploration of the effects of different designs for guided exploratory learning, 2) and evaluation of the effectiveness of educational activities by studying the presence and quality of the learning processes visitors are engaged in.

The identified research areas related to evaluation are considered in "*Proposing an evaluation framework for interventions: focusing on students' behaviours in interactive science exhibitions*" (Hauan, DeWitt, & Kolstø, 2015), included in the current study. To find expedient ways to evaluate exhibition-based programmes, we designed paper-based material for self-guided exploration. Eleven to thirteen-year-old students participated in the study. The programme design is based on a conceptual framework developed with the aim of creating a learning environment which embeds kinaesthetic, text-based, verbal, and social experiences to facilitate progress towards conceptual understanding, via the use of group assignments through which students experience phenomena corresponding to particular scientific concepts. The programme consisted of six tasks, five customised for energy-related exhibits, and one which gave teachers the opportunity to support students in understanding the relationship between the concepts they encountered. The evaluative approach focused on students' verbal and non-verbal behaviours and related identified behaviour categories to learning theory. Video recordings were transcribed and analysed, investigating the quality of the intervention based on both verbal and non-verbal behaviours during the six tasks. The proposed evaluation framework consisted of two identified overarching learning related behavioural categories. One behaviour

category reflects general overall engagement in the learning environment and the second, designated as Multi-Modal Discussions, is indicative of deeper engagement and, in turn, the possibility of conceptual learning outcomes.

Applications of the evaluative framework are investigated by a third study, presented in the current paper, "*Comparing resources for self-guided learning in interactive science exhibitions: evaluations based on students' behaviour*" (Hauan & Hällman, submitted 2016). For this study, we incorporated behaviours categorized with the evaluative framework proposed in Hauan et al. (2015) into evaluation software designed to code video recordings. This software configuration rationalizes the process of analysis. For this research, we investigated four designs for self-guided exploration of the same five exhibits as in the previous study. Two designs can be described as low in terms of sophistication: one encourages open exploration while the other involved a "classical" worksheet. The third design was identical to the paper-based material design developed in Hauan et al. (2015). The final design involved digital, multimedia tablets and included all the features of the paper-based version. Moreover, this design encouraged photography of relevant objects and phenomena and allowed for feedback and score-based responses. The findings suggest that designs for self-guidance can indeed influence students' behaviours and that an application of the evaluative framework results in data which can be used to compare and discuss differences in the educational quality of the designed materials. Additionally, the research suggests that the group behaviour of students is greatly influenced by the design of the materials. This influence resulted in the inclusion of group behaviour as an additional category in the evaluative framework. Our experience analysing extensive data from 14 visits also suggests that the applied software is an expedient tool for evaluations of educational quality.

A conceptual framework for designing material for Guided Exploratory Learning experiences is presented by Hauan et al. (2015) and also applied in the design of the digital version, presented by Hauan and Hällman (sub. 2016). The theoretical foundation for the conceptual framework, discussed in detail in chapter four, presents a theoretical rationale for the design of learning activities that facilitate Guided Exploratory Learning. The design aims to guide students in the reading of texts which present focal concepts, multisensory observations of related focal phenomena and objects, and linking concepts to previous experiences. These experiences result in joint, explorative task-solving; reflective exploration by scaffolding students' thinking, and they provides guidelines that aim to facilitate students' personal engagement. The result of comparing programme designs by applying the developed evaluation framework (Hauan & Hällman, sub. 2016) suggests that the design of Guided Exploratory Learning significantly enhances the educational quality of visits. As we worked with the design concept of the current study, we developed a perspective that considers the users of programmes as educational resources. Furthermore, these resources ought to be given the same weight as resources provided by the venue. This perspective has led to the design framework I have termed *Embedded Learning Environment*. The idea implies a shift from focusing on what an exhibition has to offer to how an exhibition and visiting teachers' and students' resources can be embedded in a holistic learning environment. An Embedded Learning Environment requires that designers cull knowledge concerning visitors and, in particular, gather information about students' prior knowledge and experience with relevant concepts, in addition to information about school curricula and textbooks.

The current study suggests that the evaluative framework proposed, based on students' behaviours, can be expedient for the evaluation of the educational quality of material designed for self-guided, exploratory, learning experiences in interactive science exhibitions. The study also suggests that the design of self-guided learning experiences can result in structures which embed the educational resources of teachers and students and can indeed lead to experiences that support students' progress towards conceptual understanding.

List of publications

Hauan, N. P., & Kolstø, S. D. (2014). Exhibitions as learning environments: a review of empirical research on students' science learning at Natural History Museums, Science Museums and Science Centres. *Nordic Studies in Science Education*, *10*(1), 90-104.

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Hauan, N. P. & Hällman, A. K. (submitted September 2016) Comparing interventions for self-guided learning in interactive science exhibitions: Evaluations based on students' behaviour. Submitted to *Visitor Studies*

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Hauan, DeWitt & Kolstø (2015) is an Accepted Manuscript of an article published by Taylor & Francis in Journal of 2015 on 26 Oct 2015, available online: http://wwww.tandfonline.com/DOI. All rights reserved.

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1. Introduction

Motivation and background

My early professional training as a sailor and in oil drilling involved both practical on-the-job training and classroom training. After my Bachelor degree, my Masters included a large amount of work in a laboratory. My next employment was as an engineer in the paper-production industry, which also involved a steep learning path which closely linked theory and practice. During later work as a high-school teacher, I began to reflect on this background. The reflections revolved around the apparent challenge students faced in using theoretical training in the practical problems I presented them. As a father, I also gained insight into the lack of practical experiences provided during both primary and secondary school. These insights and a resulting wish to help schools to provide practical experiences have motivated my current work at the science centre VilVite. A major part of my work at VilVite is to develop exhibitions and individual hands-on exhibits. Exhibit development is a complex process involving team-work and aims to provide visitors with an opportunity to explore objects and phenomena in a way that supports their conceptual understanding or triggers curiosity. To generate understanding and curiosity, these exhibits demand some degree of focused attention by the visitors. My observations during my first years in this field indicated that such focused attention seemed to be achieved by leisure time visitors such as families, however, for school classes, this was less apparent. VilVite has developed worksheets with the aim of enhancing students' focus and linking experiences in the exhibit to school curricula. These worksheets that were designed to engage students to respond in writing to questions, are popular among teachers, however, they do not seem to engage students and tend to be left behind in the exhibition, uncollected by teachers.

Currently, VilVite is one of ten science centres in Norway. School-based programmes for most of these centres are focused on activities which take place outside of the exhibitions and are similar to school-based laboratory and workshop activities. Exhibitions may be used in a limited way for curriculum-based activities because there exists a lack of design frameworks to guide utilization of their potential. Another reason is the tradition which considers science centre exhibitions as places where visitors should freely follow their own interests. Through participation in the European Collaborative for Science, Industry and Technology Exhibitions (Ecsite) conference, I learned this is a widely-held view and is often described using the term *informal learning*. Informal learning perspectives generally see science centres as an alternative to schools and hold a resistance towards adopting school focused perspectives. A commonly presented argument is that school learning is superficial and focused on achieving high test and exam scores, while science centre learning is about in-depth learning for real world applications. My previous attempts to promote curriculum-based exhibition programs have often resulted in strong emotional resistance, prompting reflection on what I have learned about different paradigms and the challenges of bridging them.

Discussions with colleagues in Europe provided little insight or guidance related to the challenges of designing exhibition-based learning activities for schools; neither did my professional training nor experience as a teacher. I therefore began to ask my colleagues about literature concerning science centres and learning. The most frequently recommended book was "*Learning from Museums: Visitor Experiences and the Making of Meaning",* in which, based on extensive analytic and empirical research, Falk and Dierking (2000) present the Contextual Model of Learning (CML). By listing exhibition design as one of eight factors that influence learning, the CML altered my perspectives on exhibition design and its influence on learning. The book was compelling; however, I often felt stuck in terms of guidance for designing exhibits for school use when, for example, I read statements similar to the following: "*In the long run, though, schools may not be the most natural [...] to partner with, given the different cultures and realities of free-choice and compulsory learning*" (Falk & Dierking, 2000, p.227). Another highly recommended book was "*Learning in the Museum*" by Hein (2002). In line with Falk and Dierking (2000), Hein (2002) argue that free-choice visits, where a visitor decides what to engage with, is most appropriate for museums, as opposed to visits where the content and learning agenda are defined by a teacher or other educators. Falk and Dierking (2000) prefer the term *free-choice* rather than *informal*; however, both Hein (2002) and Falk and Dierking argue for informal learning. Their texts define what is often labelled *informal learning* as a paradigm at play for learning in museums and other venues such as science centres.

Although my knowledge concerning learning in areas such as science centres was broadened by reading these books, they provided limited guidance in terms of a focus on schools. I turned to Frøyland (2010), who takes a school-focused perspective on out-of-classroom environments, including science centres. Basing her thinking on theories about learning, Frøyland (2010) presents a number of museum and science centre related studies, further aiding me in my search. I found additional studies in a report from the Research Council of Norway (RCN) (Nordal, 2010), which presented and discussed the status of research on science centres in Norway. Nordal (2010) argues that, for visits to be prioritized for schools, these visits must be structured in a way that ensures students are engaged in predefined, curriculum-based activities. The RCN report calls for research projects that provide insight to guide the development of national strategies to incorporate science centres as resources for schools.

Motivated by a wish to facilitate the use of science centre exhibitions for schools and informed by insight and knowledge gleaned from the literature discussed, I began the current study with the aim of answering the following question:

> How can science centre exhibitions be used as a resource for school curricula-based learning in a way that safeguards the uniqueness of such exhibitions, engaging educational explorations of science?

To address this research question, I wanted to use theory of learning, research in science education focused on a school context, and research on museums and interactive science exhibitions.

Reviews by DeWitt and Storksdieck (2008), and Rennie (2007), provided guidance for the study and helped in focusing the research. Both reviews emphasise the significance of pre- and post-visit activities in the classroom. As these reviews also provided guidance concerning the design and facilitation of such activities, we followed guidance proposed by these reviews concerning the design and facilitation of such activities and focused on taking this into account when designing programmes for interactive science exhibitions.

Both DeWitt and Storksdieck (2008), and Rennie (2007), note that the design of programmes should reflect that venues such as science centres are environments designed to facilitate educational experiences which are influenced by visitors' personal motivations and interests. This is challenging as the goal of visits based on school curricula may not correspond to students' personal motivations and interests. The implication of this challenge and approaches to its solution in the context of science centres are key aspects of the current study. A related question, raised by DeWitt and Storksdieck (2008), addresses the nature of science centres and schools' use of such venues, asking how we can involve visiting students and teachers in the development of engaging learning programmes. Similarly, a review by Bransford, Brown & Cocking (2000) argues that educators need to take into account learners' background and interests in school settings. Bransford et al. (2000) is one of the resources considered as a guide for determining methods to enhance the educational quality of visits through the design of learner-centred visits.

Rennie (2007) notes that interactive explorations of exhibits does not guarantee an educational experience. Similarly, Millar (2004) reports that interactive explorations of equipment in school laboratories does not necessarily result in science learning. Rennie (2007) argues that the design of programmes for exhibits requires a consideration of the strengths and limitations of exhibitions as means to support development with the goal of understanding. Millar (2004), with respect to ways in which practical work can support development of conceptual understanding, provides a perspective for analysing educational quality of exhibit-related activities and for guiding development of such activities.

Finding feasible methods to evaluate the educational quality of visits to venues such as science centres is challenging. DeWitt and Storksdieck (2008) consider this evaluation to be highly significant for guiding further research. A similar challenge is presented by Hofstein and Lunetta (2004) who report that feasible methods are also lacking to evaluate the quality of practical work in school laboratories. As Rennie et al. (2003) remind us, learning is an individual and cumulative process; moreover, measuring the educational value of a visit, as an element in a range of learning situations in classrooms and other environments, is challenging. Rennie et al. (2003) have suggested a learning process perspective for evaluating the quality of a visit, which guided our search for feasible quality evaluation methods.

2. Summaries of papers

This chapter presents summaries of studies of the PhD project.

2.1 Exhibitions as learning environments: a review of empirical research on students' science learning at Natural History Museums, Science Museums and Science Centres. (Hauan & Kolstø, 2014)

The current PhD project arose from concerns around how best to use the educational potential of interactive science exhibitions to support students' progress towards conceptual understanding. This implies that the project is founded on the hypothesis that an exhibition has the potential to be an educational resource. To investigate this, we reviewed empirical studies on schools' use of exhibitions and educational activities at natural history museums, science museums, and science centres, and learning-related experiences provided by visits to such venues. Key words used in the initial search were; *learning, science, museum*. To ensure the quality of papers included, the literature search first employed the ISI Web of Knowledge. We then expanded the inclusion criterion to results from searches in the databases of journals found in the references of research found in the initial search.

The visit structure and the degree of students' influence on the structure during visits were found to significantly influence the educational potential of exhibits. Based on the papers reviewed, we argue that educational activities should provide both freedom of choice and structure in order to facilitate both personal motivation and focus on relevant activities, observations, and concepts. Based on literature concerning learning facilitation, we also argue that clear rules and goals for exploration need to be presented. Findings in the studies reviewed and guidance from literature on learning lead to the claim that designed interventions should both guide students in their exploration of material presented to them during visits and provide them with freedom of choice (within the structure provided). We designate this design principle

Guided Exploratory Learning (GEL). The papers reviewed present conflicting views from researchers, teachers, and students concerning methods of guidance (e.g. through staff, worksheets, information and communication technology (ICT) equipment) and their effects on learning, in addition to requirements for structure. These conflicting messages provide limited support for the design of material to guide student exploration. We therefore argue that continued research is needed in this area.

The studies reviewed present a range of methods for evaluating the quality of visits from a learning perspective. Educational quality has been evaluated by analysing observations of students during visits, concept maps and written texts produced by students, students' responses to questionnaires and interviews, and the opinions of students and teachers regarding student learning. We argue that basing an evaluation of educational quality by measuring the educational outcome of a visit is rarely viable. This argument is based on the following: first, it is demanding as it requires a thorough evaluation of existing conceptual understandings and an evaluation of how these understandings have changed as a result of a visit. Second, focusing solely on a visit disregards understandings of learning as a complex process which requires time. It also fails to capture the influence of related learning activities, such as pre- and post-visit activities carried out in school. We therefore argue for evaluating the educational quality of a visit by focusing on the visit itself, identifying activities which are fruitful elements in exploratory processes which promote conceptual understanding. Our claim is that this process-based perspective may facilitate the documentation of beneficial learning processes during a visit and that further research within this area would be of significant value.

Overall, the studies included in the literature review support the argument that visiting an exhibition at a science communication venue can support science learning. The review suggests that the degree to which this potential is realised is dependent on how the visit is designed. We identify two possible areas which may prove insightful for further research, namely, an exploration of the effects of different designs for guided exploratory learning and an evaluation of the effectiveness of educational activities by studying the presence and quality of learning processes that visitors are engaged in.

2.2 Proposing an evaluation framework for interventions: focusing on students’ behaviours in interactive science exhibitions. (Hauan, DeWitt & Kolstø, 2015)

In this study, we follow up on a claim from the first paper presented in this PhD project (Hauan & Kolstø, 2014) which pointed to the need for further research in evaluating the educational quality of visits from a process perspective. To this end, we conducted a research study which involved designing an intervention for guided explorations of specific exhibits and a summarizing task. Design of the intervention followed design principles developed in the first paper, GEL. This design principle involves guiding students' interactions with a learning environment. As discussed in a section of the article titled "*Conceptual framework for intervention design*", material handed out to students aims to guide their interactions with what we consider to be the four principle elements of the learning environment: exhibits that present focal phenomena, texts that present scientific concepts, students within groups and their teacher, and students' existing cognitive structures. Students worked in groups and teachers were assigned the role of supporting these groups in their work with a summarizing task. Students' activities during this intervention were recorded by video cameras strapped to students’ heads or chests, detailing the activity of four groups of 11–13-year-old-students from four different schools. By analysing the video recordings, we addressed the following research questions:

1. What categories of verbal and non-verbal behaviours are generated by the educational material provided to students during their visit to the science centre?
2. Are these behaviours consistent with behaviours that are recognised as supporting the development of conceptual understanding?

Transcripts were created to represent students' verbal and non-verbal behaviours. Analysis of the transcripts resulted in a structure of codes which describe students' behaviours. Two overarching, learning-related, behavioural categories are identified:

One category reflects the overall engagement in the learning environment and is considered as indicative of the *preparation for future learning,* a concept developed by Bransford & Schwartz (1999).

The second category is found to be consistent with deeper engagement in the learning environment. To describe and discuss this behaviour category, we developed the concept of *Multi-Modal Discussions* (MMD), describing behaviours that are elements in a discussion and include a range of verbal and non-verbal behaviours. In line with Mercer we employ the term MMD to describe "*co-ordinated intellectual activity*" in which the students are engaged in work with given tasks. Moreover, and in agreement with Wertsch (1991), we argue that exhibits, provided material, and the other students which together with each student's prior knowledge define the learning environment, can all be seen as elements in a tool kit for learning. Behaviours within the MMD category are considered indicators that learning is likely to be occurring. At the same time, although our argument that MMD is consistent with concept learning and is based on previous research on learning, it should still be considered as a hypothesis.

In response to the research questions, the data suggest that materials distributed to the students (and used during their visits) encouraged behaviours indicating that students were being prepared for future encounters with focal concepts, and that learning was likely occurring, and there were few instances of off-task behaviour.

The findings also indicate that the designed tasks enabled students to take advantage of the learning environment by using it to develop and test propositions related to the subject matter, supporting their progress towards conceptual understanding. Conceptual learning is a complex process that typically extends over a long period of time. Consequently, we argue for taking a process-based perspective when evaluating visits as potential learning experiences, rather than a narrower focus on learning outcomes. We claim that the evaluative framework presented in this article also can contribute to the development of methods to make quality evaluation feasible for science centre staff and researchers. However, as it has only been used for this particular case, its applicability should be considered as a *working hypothesis* (Cronbach, 1975). The evaluative framework should therefore be subject for evaluation and possible modifications of its structure of included behaviours when applied in other cases.

Finally, the investigation of learning-related behaviours generated during visits is also informative about how a given design works. Therefore, we claim that the findings of this piece of research can also contribute to knowledge building within science centres concerning the design of material for guided exploratory experiences to promote conceptual understanding.

2.3 Comparing handed-out materials for self-guided learning in interactive science exhibitions: evaluations based on students' behavior. (Hauan & Hällman, submitted 2016)

This study investigates a working hypothesis (Cronbach, 1975) concerning the applicability of the evaluative framework presented in the second paper (Hauan, DeWitt & Kolstø, 2015). The study also addresses how the design of interventions shapes students' behaviour. To accomplish this, we applied the framework to four different designs of material that was handed out to groups of 11–13-year-old students. All four designs involved the same set of interactive exhibits and a summarising task. Two of the designs can be characterized as follows: one type encourages open exploration while the other involves traditional worksheets. Two other sets of materials were designed in line with the design principle of GEL from the first paper (Hauan & Kolstø, 2014), which was further elaborated on in the conceptual framework for intervention design in the second study. In this third paper, one GEL-based design was identical to that presented in the second paper. These materials guided students’ exploration of exhibits and facilitated joint task-solving activities, aimed to support students’ linking to prior experiences, and attempted to scaffold students' thinking. The other GEL-based design involved the same tasks presented in the second paper (Hauan, DeWitt & Kolstø, 2015) but used digital multimedia tablets. Moreover, it had features which gave students feedback and tasks were expanded by the open-ended sub-task of taking photos.

The activity of 14 groups from 12 different schools was video-recorded in this study. The framework containing categories and codes for various types of behaviour (developed in the second paper), was integrated into software for the direct analysis of video recordings. By analysing behaviours that were recorded, we aimed to answer the following research question:

> How do differences in design of resources for guiding exploration on school trips relate to observed learning-related behaviors?

The comparison of results from analysis of the open exploration and traditional worksheet designs with those from the GEL-based designs suggest there is a significant difference in the designs' abilities to engage students in the learning environment, indicating a likely difference in resulting preparation for future learning. Statistical analysis using the Chi-square test found that GEL-designs have the best results, as characterized by the framework. There are also large variations in the observed organization of groups. This is particularly evident in the conduct of self-appointed group organizers. The encouragement to include all students provided by the GEL-based designs led the self-appointed group organisers to strive to involve all group members. This fruitful group organizing behaviour was not observed in groups using the other types of design (e.g. open exploration and traditional worksheets).

All four types of design seemed to support behaviours categorized as contributions to multi-modal discussions (MMD), but the extent and variety of results suggest that GEL-based designs may have led to a greater frequency of fruitful MMD.

Overall, the findings suggest that all four designs promote learning for some students. However, there are differences in the designs' abilities to facilitate joint group work, produce overall engagement, and generate deep engagement in the learning environment.

Our analysis also suggests that the framework we used to categorise behaviours is useful for the evaluation of the quality of designs (in promoting learning). This study demonstrates that for a framework to capture educational quality it should at least investigate the characteristics of group interactions, teacher involvement, initial engagement with exhibits and scientific texts, and extent and quality of MMD.

The applied framework results in little information related to linkage to students' prior experiences. This should be a subject for further research. It is also revealed that further research is necessary concerning the possibilities of digital technology.

3. Methodology

This chapter presents a background on the methods used to conduct this study and discusses their application.

The following abbreviations are used to improve readability:
Paper-I for Hauan & Kolstø, 2014;
Paper-II for Hauan, DeWitt & Kolstø, 2015;
Paper-III for Hauan & Hällman, submitted 2016

3.1 Clarifying my position

My motivation for working at a science centre is related to my previous employment as a teacher. My focus is supporting schools by providing learning activities which involve observation and manipulation of real objects, and facilitating reflection on these activities. Development of exhibitions is one of my responsibilities at the science centre and a goal has been to design exhibits in line with schools' curriculum in order to potentially make them a useful resource for schools. The goal of this project is to explore and use this potential to support students' science concept learning, doing so in a way that preserves and exploits the engagement that visiting students express during visits.

3.2 Reflections on methods and application

The following sections present and discuss methods used in the three studies included in this thesis.

3.2.1 Literature review by Hauan and Kolstø (2014)

As employees at the science centre VilVite we have searched for literature that can provide guidance to increase the potential of exhibitions as educational resources for curriculum-based learning. We found that the potential to be an educational resource for schools is recognized by some researchers (e.g. Rennie, 2014) and questioned by others (e.g. Falk & Dierking, 2000). However, little research has been completed within this field in Norway and none at my current university. Consequently, my supervisor wisely recommended that I begin by writing a review paper concerning empirical research on science centres and similar venues. The review study aimed to gain knowledge from existing empirical studies, relate the findings to theories on learning, and thereby develop a plan for future studies.

Two main concerns guided the selection of studies for the review. First, to ensure the quality of selected studies, only peer-reviewed studies were included. Second, to ensure repeatability in the selection of studies for inclusion, we applied precise selection criteria so others who applied these criteria could identify the same papers. Initially, we included only studies published in journals listed in the database ISI Web of Knowledge and identified with selected key words. After reading the identified papers, we found that some papers referred to studies presented in journals other than those included in ISI Web of Knowledge. After reading some of these referred studies, we concluded that some were highly relevant. To include these studies and maintain repeatability, we updated our search criteria to also include specific journals and named these journals in the methods section of our paper. All papers identified were then read to determine their relevance. To include a maximum number of articles, we did not apply criteria for methodologies used. Thus, we included findings based on end-of-visit tests, teachers' impressions, student interviews, analysis of student assignments, questionnaires, concept-maps, and personal-meaning-maps, in addition to studies documenting activities and processes believed to characterise productive learning processes. The process of inclusion and exclusion and applied criteria are presented in the paper.

Before categorizing findings and determining patterns, the included papers were thoroughly read to gain a deep understanding of the studies. During this time, descriptive notes were written concerning identified findings. A one-page summary was then made for each paper. Each summary describing: 1) the context and features of the study, 2) types of learning materials, 3) types of data collected, 4) method of analysis of data, and 5) the main claims and findings. The analysis of paper summaries was conducted from a design perspective, wherein we identified findings related to how the design of exhibitions and methods of mediation between students and exhibitions affected the resulting learning situations. The findings were labelled with code names to describe relevant characteristics. The process of assigning descriptive codes involved initiating a process which, within literature concerning *grounded theory*, is designated as *the constant comparative method* (Strauss & Corbin, 1990). This allows coding and analysis to be joint procedures. The process involves comparing findings in reviewed papers, searching for similarities and differences between codes, and reviewing and re-reviewing the codes by relating them to the analysed data and tentative categorization. This ensures that the codes and coding structure are grounded in the data. Findings with similar characteristics were identified, clustered, and assigned descriptive sub-category names. These sub-categories were then compared and clustered in overarching categories. The processes of clustering, categorizing, and naming also involved a dimension of analytic work, namely awareness of "*theoretical sensitivity"* (Strauss & Corbin, 1990). This promotes an awareness of researcher's prior conceptions resulting from having read others' work within the relevant field of research and personal experience. Identifying and being aware of my prior conceptions enables comparison with conceptions developed while analysing and categorizing findings from reviewed studies. The work of identifying findings and categorizing, which involves applying the constant comparative method and being aware of theoretical sensitivity, resulted in a structure of sub- categories and main categories which became the structure of the findings section of Paper-I. One example is the sub-category "*The Use of Technology*" which emerged from comparing studies and encompasses a theme that is considered relevant for discussions concerning the facilitation of learning. Another is "*The Use of Narratives*", developed from the interplay of comparing studies and prior conceptions from reading literature. Comparing the studies resulted in the idea that two studies described significant methods to facilitate learning with common features, and finding and naming what these methods had in common was influenced by prior reading concerning narratives (e.g. Bruner, 1996; Falk & Dierking, 2000). After identifying sub-categories, we compared studies to investigate what we could learn from the different findings overall. The results of this comparison are discussed in the findings section of Paper-I.

3.2.2 Common context, motivation, and features of empirical studies.

Empirical studies involving designed interventions (Hauan, et al., 2015; Hauan & Hällman, submitted 2016) were conducted at VilVite, Bergen science centre. VilVite is situated in the centre of Bergen, a relatively small city in the western region of Norway. The municipality of Bergen has roughly 275,000 inhabitants and about 350,000 people can reach VilVite within an hour by car. Annual visitors number roughly 120,000, including 40,000 students. Most students in Bergen visit VilVite several times while in school and all students included in the study had been there before, some more than once. This implies that school use of VilVite differs from, for example, large national venues which students may visit only once a year. Participating classes came from public schools in different boroughs of Bergen. The majority of students in Bergen attend public school, thus participating students were representative of the homogeneous population of the region. Students involved in the research were between 11- and 13-years-old. All schools follow the national curriculum.

As expressed by the research questions, the purpose of Paper-II and Paper-III is to investigate behaviours generated by designed interventions and materials and to scrutinize these behaviours to see if they align with behaviours recognized as informative in relation to learning. Both studies therefore involve a quality evaluation of designed interventions with a focus on student behaviour.

The following is a short discussion of studies related to quality evaluation in exhibition contexts. One perspective on quality evaluation suggests probing for acquired knowledge. Anderson, Lucas, Ginns, and Dierking (2000) employ this approach by applying theory presented by Ausubel, Novak, and Hanesian (1978), developing a framework for pre- and post-testing including use of concept mapping to investigate the development of conceptual understanding. Others have developed less resource demanding concepts for pre- and post-testing, such as the *Personal Meaning Map* (Falk, Moussouri & Coulson, 1998). Watson (2010) also used pre- and post-testing to investigate the influence of elements in an educational intervention. The use of pre- and post-testing has given rise to concerns: it is resource demanding and including a pre-test may activate prior knowledge (Ausubel et al., 1978), therefore enhancing the learning outcome and influencing the test results. Pre- and post-testing can also be challenging as it is also inadequate to capture the effect an experience may have across long periods of time (Falk & Dierking, 2000; Stocklmayer & Gilbert 2002). In addition, pre- and post-testing typically provides little information which informs redesigns of educational material. Another perspective for evaluation is presented by Schauble, Leinhardt, and Martin (1997), and argues that "*understanding learning means studying in detail how it unfolds*" (p. 4). This perspective is described by Rennie, Feher, Dierking, and Falk (2003) as a process perspective. One study employing this perspective is that of Barriault and Pearson (2010), wherein they describe the development and use of a tool called the Visitor Engagement Framework (VEF). The VEF is a promising tool; however, it was developed for the evaluation of exhibits which we understand as only one of the elements in a holistic learning environment. Another difference between the current study and the VEF is that it examines *free-choice* visits implying that visitors' motivation for visiting and engaging with exhibits is based on their personal interests and agendas and not by teachers or school curricula (Falk & Dierking, 2000). Another project that uses a research method similar to an evaluative method is that of Allen (2002), whose analysis of *free-choice* visits focuses solely on visitors' dialogues, using categories of "*learning-talk"* (p.277). These pieces of work, from both Barriault and Pearson (2010) and Allen (2002), helped to inspire the current study. However, we wanted to investigate interactions with both exhibits and material provided for self-guidance. Consequently, we did not want to restrict our investigations of students' interactions to dialogue. We therefore needed to look for brother methods to study behaviours arising from designed interventions. This guidance was found in a study by Rennie, Feher, Dierking and Falk (2003), which notes that

> *Video-clip analysis, observation, interviews, and audiotaping conversations all provide insights into the learning process, enabling closer attention to the individual, the individual's interactions with objects (exhibits, animals, books, movies, and so on), the individual's interactions with others, and interactions among members of a group. (p.117)*

This finding led to the selection of a method described by Jordan and Henderson (1995), designated *Interaction Analyses,* which embraces the perspective that learning results from human interaction with others and materials in a specific learning environment. Jordan and Henderson (1995) also remind the reader that, due to the nature of the data, interaction analyses cannot reveal what is happening in the heads of students. Assumptions can only be made based on what is observable. This implies that one cannot see that learning is happening by observing student behaviours, rather, observed behaviours only have potential as indicators of learning. The principle of interaction analyses suggests that interpretations and developed theories are founded in observed behaviours, thus, a *grounded theory* (Strauss & Corbin, 1990) perspective is applied in the analysis.

***Design experiment*:** The nature of the current study, to investigate designed interventions, aligns with a description by Cobb, Confrey, diSessa, Lehrer, and Schauble (2003) concerning *Design Experiments.* They state that "*design experiments ideally result in greater understanding of a learning ecology—a complex, interacting system involving multiple elements of different types and levels* […]" (p. 9). This statement aligns with the aim of studying behaviours that result from a learning ecology defined by elements of a holistic learning environment, the subject of the current study, and discussions as to whether these behaviours can be seen as indicators of learning-related activities. We also find that features of the current study correspond to key features of design experiments as described by Cobb et al. (2003). This feature can be described as the investigation of designs that aim to support students' learning processes. The design of interventions is based on literature on learning and prior empirical research to gain perspectives from an existing knowledge base. The study takes two approaches: first, designing for something to happen, and second, reflective, by studying what happened. We aim to develop theories that are humble in the sense that they acknowledge that their applicability must be considered as rooted in their origins, namely facilitating student learning in interactive science exhibitions. The study aims to generate benefits by building on knowledge about facilitating learning in a specific setting.

In agreement with the requirements of Cobb et al. (2003), the research team consisted of a researcher who became the first author of the resulting papers (the author of this thesis) and supervisors who were experienced researchers and co-authors of resulting papers. Findings and results were discussed with researchers on the team and others within the university where the research was organized. A pilot study involving teachers and science centre staff was performed as part of the design process, also in accordance with Cobb et al. (2003).

Data collection: As discussed by Rennie et al. (2003), a number of methods for gathering data from interactions exist, including interviews, observation, and audiotaping. In agreement with recommendations from Jordan and Henderson (1995), the current study employs video recording. The advantages of video recordings are that they have the potential to capture the richness of interactions and that they record activities as they occur. They are not influenced by interpretations from an interviewer or observer, can be observed repeatedly, and can be presented to others as raw, uninfluenced data. We decided to record students' behaviours by attaching video cameras (camera model: GoPro Hero3) to two students in each group being observed. Through pre-trials, we found that strapping cameras to students' chests provided better recordings than the forehead. Recordings from head mounted cameras gave less information about the behaviour of others within the groups. During pre-studies, the researcher was in the exhibition while the classes performed the tasks, writing some notes. The researcher's presence became problematic as students and especially teachers wanted to discuss the tasks and other related topics with the researcher. From the pre-studies, we also learned that camera recordings provided the necessary audio and visual data and decided to base our analysis on only these recordings.

Video recording and data storage were conducted in accordance with requirements defined by Norwegian Centre for Research Data (SND) (http://www.nsd.uib.no/nsd/english/index.html) and the project was registered in SND's database. The document, *Consent for participation in the study*, was signed by the guardians of participating students. The names of participating students were not registered, thus names in the presented transcripts are pseudonyms. The participating schools and teachers were not stored together with, or in the same database as, the recorded data. Recorded data were transferred from the cameras and data in the cameras deleted. The data were stored in external hard-drives in locked steel compartments.

3.2.3 Empirical study by Hauan, DeWitt and Kolstø (2015)

Intervention design: The process of designing and piloting the intervention was guided by the goal of facilitating activities within the conceptual framework developed for the study. The pilot involved students and teachers (in target grades for the design) who were not involved in the main study.

To discover whether exhibits facilitated *exploration of phenomena,* we invited students to freely explore the exhibits. Student explorations were closely observed by VilVite staff who had been instructed as to what to look for. These tests informed us that some exhibits failed to facilitate the intended observation of phenomena when the exploration was unguided. In response, we redesigned exploration guidance to fit the identified need. We strived to achieve an optimal balance between open exploration and structured guidance. This optimization of the guidance level was informed by ideas around Guided Exploratory Learning (GEL)*,* as described in Paper-I. The guidance was indirect and implicit, forming part of the text in the materials. Of relevance for *anchorage* (Ausubel, 2000), students' prior knowledge of related subject matter and their ability to relate the exhibits to their everyday experience were also investigated through observation and in immediate follow-up interviews. These observations and interviews informed us that some exhibits were more difficult to relate to students' prior experiences than others. Some students had misconceptions related to some of the exhibited phenomena and the function of some exhibits was misunderstood. To support linking to prior experiences (see chapter 4.2.3), we designed supportive illustrations by modifying illustrations found on the internet via www.google.com. The type and design of tasks were customized to avoid eliciting prior misconceptions which interfered with student learning or confirmed those misconceptions. Our observations of and interviews with students are concisely reported as notes in the published paper.

The national curriculum does not list all the concepts included in the textbooks used by students; and textbooks from various publishers include different concepts and in different grades. The inclusion of relevant concepts necessitated reading the three most common books used in schools in the local municipality of Bergen. *Reading involving focal concepts* was facilitated implicitly by including concepts in the texts of exhibit related task-sets, and in this way, created a potentially meaningful context which required reading to solve tasks. The focal concepts were also included in the summarizing task with a *concept flow chart*. These methods of presenting concepts were inspired by Wellington and Osborne (2001). All tasks instructed that all individuals to participate with their proposals, with the aim of including all students in *group work* to result in fruitful explorative discussions, as described by Mercer (2000). The overall structure of the intervention and tasks was informed Paper-I. We aimed to structure students' exploration in a way that guided them to use all educational resources, including peers and teachers, and allowed students to control how they made use of the resources available.

A draft of the completed task-set was sent to two teachers for feedback. They commented on issues such as the complexity of language, length of texts, and layout. After incorporating changes based on teachers' feedback, the task-set was then tested on a class of students. The task-set was then finalized after a few adjustments based on students' comments.

Analysis: Grounded theory was chosen as the method for data analysis because, first, its aims cohere with those of design experiments. Moreover, grounded theory involves the development of theory (Chism at al., 2008), an aim for design experiments (Cobb et al., 2003). The other reasons for choosing this strategy are related to trustworthiness and challenges involved in the described background and motivation for the research, namely, grounded theory provides guidance that helps to avoid interference with the initial analysis arising from researchers' perspectives and interests (Strauss & Corbin, 1990). However, as a researcher entering a field has specific knowledge and prior conceptions, it is naive to think that transcripts and analyses are conducted with total objectivity (Mills, Bonner & Francis, 2008). The inherent conflict, resulting from, on the one hand, constructing a situation, and, on the other hand, striving for open-mindedness in the inductive process of knowledge building through analysing this constructed situation, is discussed by Charmaz (2000). She argues that awareness of this conflict and applying methods to approach it ensure the validity of the research. Charmaz (2000) calls this approach, an approach which we also consider as categorizing our research, the *constructivist grounded theory*. To address this issue, Strauss and Corbin (1990) use the term *theoretical sensitivity*, which denotes awareness of the fact that, as an educated person in a given field, a researcher has ideas of what to expect from data, and that this expectation influences analysis. Awareness of the influence of *theoretical sensitivity* has helped me to avoid the influence of my prior conceptions and interests during initial phases of research, i.e. transcribing the recorded videos (Jordan & Henderson, 1995), by focusing on being simply descriptive while transcribing students' and teachers' verbal and non-verbal behaviours. I included behaviours that were generated by or relevant to working with the materials developed (behaviours such as how individuals stood or if they played with their hair were not included). However, unwanted and unintended behaviours were also transcribed and all affect-related behaviours included.

Following transcription, a process of "*Open Coding*" was employed (Strauss & Corbin, 1990, p.61). Open coding is the first step in analysing transcripts and results in data in the form of codes with names that describe the phenomena they denote. The process involves the close examination and conscious comparison of codes with the data they describe, and between codes within the emerging coding structure. Discrete, observable verbal and non-verbal behaviours from individual students or teachers were chosen as units of analysis. I began by coding the transcript based on video recordings of the first group of students. During the first phase of open coding, I applied descriptive code labels to all individuals' behaviours. In the next phase, I compared behaviours assigned to same code labels and found that an additional level of sub-codes was needed to describe behaviours with an adequate degree of detail. These two phases of coding development involved a continuous review of codes to evaluate their ability to precisely describe the behaviours. The resulting set of codes and sub-codes was then included in the first version of the coding manual. To enhance the accuracy of the codes and test their usefulness, we conducted "*Check-Coding*" (Miles & Huberman, 1994, p.64). This involves inviting another researcher to review the coding structure. First, I applied the coding manual to one page of the transcripts, then the manual was applied for coding by another PhD candidate who was not a part of the study. We then compared the results using a procedure described by Miles and Huberman (1994) as a *reliability check*, wherein results of two coding processes of the same data are compared. This test resulted in development of two more sub-codes and more detailed description of codes and sub-codes in the coding manual. Next, the revised coding manual was retested. The retested coding manual was then used in coding all transcripts.

Analysis involved addressing the inherent conflict of prior conceptions and open-mindedness. The following descriptions detail how this was addressed. Initially, we read through transcripts to gain an overview. This initial phase of analysis was influenced by previous conceptions built through reading literature about verbal discussions as related to learning (e.g. Allen, 2002; Mercer, 2000), in particular Mercer's (2000) categorisation of talk. Soon, it became evident that this perspective was unfruitful. Awareness of our theoretical sensitivity made us rethink this conception and search for other perspectives. This resulted in a coding process consisting of two separate phases.

The first phase of analysing the coded transcripts was theory driven (Strauss & Corbin, 1990), as it involved identifying codes related to the conceptual framework of the intervention design, developed based on what Strauss and Corbin (1990) call "*technical literature*" (p. 49), in this case, literature on learning. We began by identifying behaviour codes that were directly linked to overall engagement in the elements which constituted the learning environment. These behaviour categories included: initial observation or interaction with focal phenomena, behaviours related to reading text involving focal phenomena, and behaviours related to the organization of group work. These were not considered as indicators of deep engagement with the learning environment, but rather as gateway-behaviours for deep engagement. These gateway behaviours were classified as an overall engagement in the learning environment and as indicators of "*preparation for future learning*" (Bransford & Schwartz, 1999, p.68). The first phase also involved identifying off-task behaviours. The classification of gateway and off-task behaviours in this first phase resulted in a broad class of behaviours to describe how students used both the material provided and their peers (and teachers) to perform the tasks. The second phase of analysing the coded transcripts was inductive. We looked for concepts to interpret the interactions, basing analysis on the codes and not prior conceptions. This second phase highlighted a broad class of behaviours describing students' engagement in the tasks. These behaviours, related to learning activities discussed in the theoretical framework chapter, were considered indicative of in-depth-engagement. Identification of this class of behaviours and sub-behaviours initiated a process of reflection that involved framing identified behaviours in relation to literature about learning that had been examined. This broad class of behaviours in turn guided further reading (see literature presented in the theoretical framework section). This process, involving awareness of a broader theoretical perspective, led to reflections on the identified behaviours in relation to literature which describes using resources and activities that support the development of conceptual understanding. The notion of seeing in-depth-behaviours as contributions to MMD (Paper-II) were, in particular, inspired by Wertsch's (1991) discussion of a "*tool-kit*" (p.93) and Mercer's (2000) presentation of "*interthinking*" (p.16).

3.2.4 Empirical study by Hauan and Hällman (submitted 2016)

Intervention design: With the study presented in Paper-III, we wanted to investigate how different designs of material distributed to students for the purpose of self-guided interactions influenced their learning-related behaviour. To this end, we tested four different designs, but all encompassed the same exhibits, overall organization of the visit, and focal concepts. Our goal was to test materials with varied characteristics (informed by Paper-I), however, the required similarities restricted our ability to vary the openness of visit structure and visit agendas. All participants were given the same information prior to the study, all visits began identically, and all material that was distributed was colourful. Materials distributed included a map to help groups find the exhibits and the same summarizing task involving the focal concepts. The *open exploration* material encouraged students to explore the exhibits and discover what they were designed to convey, simply showing pictures of the exhibits and their names. The *traditional worksheet* resource was designed as a typical worksheet, with pictures of the exhibits and questions to be answered in writing on the worksheet. Tasks in the *guided exploratory learning* material on paper were the same as the one designed for Paper-II. Design of the digital *guided exploratory learning* task set was based on the design of the paper version. Additionally, we added features made possible by interactive digital technology. One of these features was to provide constructive assessment through feedback on answers to given tasks. The design of this feedback, which aims to facilitate curiosity and interest by "*providing feedback that moves learners forward*" (Black & Wiliam, 2009, p.8), was also inspired by Csikszentmihalyi and Hermanson (1995), who argue for providing "*clear goals and appropriate rules*" (p.36). Inspired by Deterding, Dixon, Khaled, and Nacke (2011) on *gamification,* the feedback was presented in the form of goblets and comments from a cartoon teacher. The gamification was moderately designed as no upper score was set. To design for openness within boundaries (Paper-I), the task set included taking pictures of what students considered to be key elements of an exhibit. Pictures taken by students were uploaded to a server and accessible for teachers after the visit to facilitate post-visit activities.

Study setup: This study responded to the conclusion of Paper-I which calls for the development of methods which would use student behaviour to evaluate quality of educational programs, and a need to test the applicability of methods for other programs. Investigating the influence of one variable, namely, the design of distributed materials, requires an attempt to control other variables to the extent possible. To accomplish this, we used the same exhibits with all designs, provided the same information prior to the visit, and attempted to conduct the trials identically e.g., wearing the same uniform. To study the interventions with multiple students, we planned to have groups from four different schools in each trial. This proved challenging and we had to reduce the number of groups in two of the four trials from four to three. The final participants included 14 groups from 14 classes in grades 6 and 7.

Analysis: The number of participating groups resulted in a large data set. To manage this amount of data, we required a tool for analysing video recordings that was more expedient than transcribing and coding. The solution was to code individual students' recorded behaviours directly, thus omitting the process of transcribing. Software developed in a project called the European Exhibition Evaluation Tool (EEET) (www.eeet.eu) was reconfigured to code behaviours and count their frequency. The codes used with EEET are those from Paper-II. In addition, because of the initial analyses and dialogues with the colleague who performed the reliability check, it was deemed fruitful to add another sub-code to better capture the details of Multi Modal Discussions (MMD).

As analyses were based on a predefined code structure developed in Paper-II, the first phase was *theory driven* (Strauss & Corbin, 1990). All recordings were analysed, including those previously analysed while developing the codes in Paper-II. To maintain focus, analysis was completed for one student at a time during the video analysis. This required recordings to be analysed for each individual student. The resulting counts of identified behaviours were then summarized and presented for each group. The analysis showed that different designs resulted in variations in overall engagement with the learning environment, including working with peers in groups. Distinct from Paper-II, to discuss differences in overall engagement, Paper-III presents initial experiences with the exhibits, initial encounters with focal phenomena, and descriptions of group behaviour. Through comparisons of behaviours seen in the video recordings, we discovered behaviour types that were not captured by the original coding-structure. This led to a phase of inductive analysis which resulted in the development of a behaviour category to capture students' group behaviours, as well as students' and teachers' overall behaviours. The written description of these behaviours can be considered as a simple form of *interpretation approach* (Miles & Huberman, 1994).

3.2.5 Discussions of methods used

In agreement with a description by Miles and Huberman (1994), the study can be characterised as a *qualitative study,* where data to be analysed comes from observations of interactions between humans and between humans and artefacts. Treagust, Won, and Duit (2014) do not use the categories *qualitative* or *quantitative* in their discussion of research paradigms because they see paradigms as concepts that go beyond the choice of data collection methods. Among the categories of research presented by Treagust et al. (2014), *pragmatic research* best matches our work, as it is characterized by a practical approach to selecting the methods to be applied. However, Treagust et al. (2014) links this category to the use of mixed-methods, which does not include the data and methods we applied. A paradigm which better describes our research approach is what the Design-Based Research Collective (2003) calls "*an emerging paradigm for educational inquiry*" (p.5), namely *design-based research*. Our study corresponds to design-based research, as described by the Design-Based Research Collective (2003) and Wang and Hannafin (2005), because the study is both guided by theory on learning and previous empirical research. The subject of our empirical investigations consisted of materials designed to guide students' explorations of exhibits. This implies that the constructed situation also involved interactions between the investigator and the participants (via the resources). Moreover, materials were designed for a specific purpose. We are therefore not merely gathering data from a situation that already exists, but are involved in the construction of a new situation, about which data was gathered. The intervention and theories that were developed were based on the application of a grounded research methodology which involved the development of analysis based on empirical data that was gathered.

The method for the investigation of the interactions is interaction analysis, as described by Jordan and Henderson (1995), who state that this method implies grounding the development of interpretations and theories in records of studied events. Basing analysis on what can be observed is in agreement with the way Strauss and Corbin (1990) define as an *inductive grounded theory approach*, applied in the development of the concept of multi-modal discussions (MMD) (Paper-II). Theory driven analyses, guided by literature on learning, were also conducted, based on the developed conceptual design framework and the concept of MMD. The situations studied were not spontaneous, but rather constructed to investigate the resulting behaviours. This construction was designed as a series of experiments which aimed to structure participants' behaviour and investigate the results. As such, the research is a *design experiment* (Cobb et al., 2003).

Overall, then, the empirical studies (Papers II and III) can be categorized as qualitative research, however, it also involves qualitative methods such as counting of behaviours to identify patterns in the results, and statistical analysis. The studies can be categorized to be within the paradigm of design-based research which investigates constructed situations and where theories developed are guided by literature on learning and grounded in observed interactions.

Reliability, validity, trustworthiness: Reliability is, as Lincoln and Guba (1985) note, related to the question "*How can an inquirer persuade his or her audiences that the research findings of an inquiry are worth paying attention to?"* (p.290). In agreement with Golafshani (2003), we consider *reliability* and *validity* to be closely related and connected to the *trustworthiness* of studies. My position, as described, may heighten the importance of the trustworthiness question, as I have had a central position in the construction of situations which are the subject of the empirical studies, analysed the resulting data, and am the first author of the papers. As discussed, Charmaz (2000) argues that awareness of the potential, disruptive influence of a researcher's position and the application of methods to increase reliability will ensure validity, facilitating trustworthiness.

We have applied several methods recommended by Chism, Douglas, and Hilson (2008) to guarantee the trustworthiness of the studies. In writing the papers, we have strived towards *transparency* through detailed presentations of the methods applied, including data collection, analysis, and the presentation of findings. Several methods advised by Chism et al. (2008) have been applied to strengthen *internal validity*. Methods for gathering and analysing data, and the results of this data, have been discussed with co-authors who are experienced researchers. The transcripts were translated from Norwegian to English by hired translators to facilitate these discussions within the research team. Discussions were held over e-mail, video conferences, and face-to-face meetings in Bergen and abroad. The research team contributed to internal validity by identifying literature that guided and supported interpretation and ensured the logic of arguments in relation to data (Chism et al., 2008). As recommended by Creswell and Miller (2000), we also triangulated our research by basing our designs on external studies and literature, and discussed our findings in relation to technical literature. Recommendations for future research in Paper-I were based on previous empirical studies and learning theory. The proposed evaluation framework in Paper-II arose from the empirical study presented, previous empirical studies, and learning theory. Results from comparing designs in Paper-III were discussed with reference to previous analytic and empirical research. The behaviour categories which were developed and used to identify learning related behaviours (Paper-II; Paper-III) were checked for inter-coder reliability (Miles & Huberman, 1994).

The inter-coder reliability check was conducted based on the coding manual developed. More specifically, an excerpt (two pages) of the transcript was coded by the first author of the papers and another researcher who was not a part of the study or involved in related research projects. The results were then compared by using a procedure described by Miles and Huberman (1994) as "*Check-Coding*". Reliability was calculated by using the formula "*reliability = number of agreements / (total number of agreements + disagreements)"* (Miles & Huberman, 1994, p.64). This test resulted in the development of a two additional sub-codes and more detailed descriptions of codes and sub-codes in the coding manual. Then, the revised coding manual was tested with a new page from the transcripts. Recalculating resulted in a reliability of 83.4% which is within the acceptance range of 70%–90% (Miles & Huberman, 1994). Advised by reviewers, we applied Cohen's kappa (κ) (Di Eugenio, 2000) reliability coefficient calculation in the report by using SPSS Statistics 22 software. The result of testing 17% of the transcripts was $\kappa = 0.783$.

A Chi-Square test were performed by using using SPSS Statistics 22 software to investigate whether observed difference in initial engagements between designs of handed out material arose by chance or were resulting from differences in design characteristics (Paper-III). Results presented in table 1. below shows that calculated significant levels were clearly different from the threshold value $p_\alpha = 0.05$ (Ary, Jacobs & Razavieh, 1996). Ary, Jacobs and Razavieh (1996) reminds that data used for the Chi-Square test must be independent. We used individual student's engagement as data for the test, based on the assumption that student's engagement was an independent variable. This assumed independence of group composition can be questioned, since one could argue that student's behaviour can be influenced by peers' behaviour. However, since results of the calculations were so distinct we would argue that any influences by the group compositions can be neglected in terms of assessment of dependence of design differences.

		Value	df	Asymp. Sig. (2-sided)
Open exploration or Traditional worksheet vs. GEL (-D or -P)	Pearson Chi-Square	57,594	3	$p = 0,000$
	N of Valid Cases	640		
	0 cells (0,0%) have expected count less than 5. The minimum expected count is 11,72.			
D-GEL vs. P-GEL	Pearson Chi-Square	1,567	3	$p = 0,667$
	N of Valid Cases	390		
	0 cells (,0%) have expected count less than 5. The minimum expected count is 5,54			

Table 1. Results of the Chi-Square tests

A two-tailed t-test were performed by using using Microsoft Excel software to investigate whether observed difference in MMD between designs of handed out material arose by chance or were resulting from differences in design characteristics (Paper-III). Results presented in table 2. below shows that calculated significant levels were clearly different from the threshold value $p_\alpha = 0.05$. We used total counted group behaviours of MMD category as data for the t-test since these behaviours results from joint exploration and not individual work. As the groups came from different classes, they were considered as independent variables.

	N of Valid Cases	t values	Sig. (two-tailed)
Open exploration or Traditional worksheet vs. D-GEL or P-GEL	14	*t-Stat =3,06* *t-Critical = 2,18*	*p = 0.01*
D-GEL vs. P-GEL	8	*t-Stat =0,58* *t-Critical = 2,45*	*p = 0,58*

Table 2. Results of the two-tailed t-test

Generalizability: The limited number of participants in the qualitative studies challenges the generalizability of the findings. A shift in perspectives on responsibility related to generalizability is presented by Chism at al. (2008) who allows the reader to make their own judgements concerning generalizability. We hope that by providing descriptions of the context of our studies and the methods used we can help our readers evaluate the generalizability of the findings for themselves. We now turn to arguments that support the generalizability of findings in the empirical studies. We begin by discussing the generalizability of the evaluation framework that was developed. Then, we discuss the findings which suggest that the design of material for self-guided exploration has the potential to guide students' engagement with the learning environment and thereby facilitate fruitful learning activity.

A key outcome from the empirical studies is the proposed evaluation framework with its set of behaviour codes. This framework was first developed, applied, and presented in Paper-II and then modified, applied, and presented in Paper-III. Chism at al. (2008) relates the question of generalizability to the applicability of findings to the cases for which it is designed. A question to be discussed, and related to generalizability, is therefore whether the evaluation framework can be applied to the corresponding cases. The framework is proposed for the evaluation of school visits to interactive science exhibitions. To discuss this issue, we will see whether our evaluation of material designs, designated open exploration, traditional worksheet, and guided exploratory learning (Paper-II), reveals similarities with findings from other interventions with similar characteristics. Studies available for comparison are included in Paper-I.

Although students were instructed to explore specific exhibits, the *open exploration* material provides a structure that has some similarities to visits which can be categorized as *free choice* (Bamberger & Tal, 2007). Bamberger and Tal (2007) report that students enjoyed free choice visits, but they resulted in little content-related talk, interactions with exhibits were superficial, and few students read labels. These behaviours are, to some extent, consistent with behaviours identified during the open exploration task set visit, where few participants noticed the names of phenomena and the fewest number of MMD were generated.

Worksheets can lead to a focus on the correct answer and are often disliked by students (Griffin & Symington, 1997; Rix & McSorley, 1999). Griffin and Symington (1997) found that less than two thirds of students worked through worksheets. This is also, to some extent, consistent with results from evaluating visits structured by the *traditional worksheets* task set which indicated that most group members did not focus on working with the worksheets and often transcribed labels to get the correct answers.

Findings by Stavrova & Urhahne (2010) suggest that the use of multiple-choice questions can positively influence students' engagement in exploration and task involvement. Multiple-choice questions and concept-cartoons, which apply a corresponding principle, were also included in the *guided exploratory learning* task sets presented on paper and digital tablets. Evaluation of visits structured by the *guided exploratory learning* task sets agreed with findings by Stavrova & Urhahne (2010), wherein students' engagement in the learning environment was increased and the task generated the most number of behaviours related to MMD.

Comparison of our findings with these cases shows that there are similarities between findings for cases with similar characteristics. This comparison suggests that the proposed framework would be applicable as a tool for evaluation of visits in the discussed studies. Arguably, this is an indication of applicability and supports the generalizability of the proposed evaluative framework. Firestone (1993) notes that researchers should discuss the conditions that limit generalizability. The proposed framework is designed for material for self-guided school visits. We do not argue for applying the framework to leisure visits because they have other characteristics, as presented by the contextual model of learning developed by Falk and Dierking (2000), or for school visits without a defined learning agenda.

Another primary finding is that material for self-guidance has the potential to guide students' observations, reading, social interactions, and facilitate linkage to prior experiences, thus supporting fruitful learning activities. This finding can be considered a theory for design which involves the design concepts of GEL (Paper-I) and ELE (Paper-III; ELE-text). The developed design theory is based on learning theory, in particular the concepts of *scaffolding* (Wood, Bruner & Ross, 1976) and *practical work* (Millar, 2004), as well as the work by Dewey (1910; 1997; 2011). The design theory is also informed by the analysis of student behaviour resulting from the designed materials.

Generalizing from our studies to broader theory involves what Firestone (1993) calls analytic generalization. In Paper-III, we present both replication studies where we strove for the same conditions and studies where the distributed material varied, changing the conditions. In agreement with Firestone (1993), we believe that the findings presented on the relationship between generated behaviours and the designs used support arguments for generalization. One could argue that students involved in design for GEL (Paper-II; Paper-III) had particular resources, e.g. intelligence or self-discipline, which helped guidance, or that they had different resources prior to visiting. The setup of the studies contradicts this argument by minimising effects from outliers by involving students from different schools and boroughs in the city. We also aimed to limit differences in preparation by providing the same information to all participating teachers. By addressing outliers and differences in our preparation, we address aspects that limit generalization, as discussed by Firestone (1993). There are, however, aspects which limit generalizability that have not been addressed. For example, it could be that students in the participating age groups are easier to guide. This suggests that the design theory should be tested for generalizability and further developed through studies with other age groups.

3.2.6 Ethics

All research involved humans, either as participants, as researchers, or in both roles, and this necessitates caution with regard to ethics. Two related aspects are discussed in the following sections.

Participants: Miles and Huberman (1994) discuss two questions related to ethics and the participants of a study. One question, relating to the time and effort invested by participants, is relevant to the current studies as the classes were given materials that were expected to be of different qualities. This suggests that there could be variation in educational quality and that some participants might receive less from the time and effort they invested. We addressed this issue by striving to optimize the educational outcome within the restrictions of the studies through an identical summarizing task for all interventions, thus including all focal concepts in all designs. However, the quality of visits differs and presumably the educational outcome varied. The second question concerns guarding participants' identities. This has little relevance for the studies as personal information was not included in the data or reports, nor did researchers have additional contact with participants other than during the visits. Discussions with teachers were restricted to the pilot study.

Worthiness: Miles and Huberman (1994) raise ethical questions related to researchers' personal motivations and agendas for a research project, the resources it demands from other stakeholders, including those who finance the project, and those who may be influenced by the results. They argue that a lack of personal motivation can result in low quality research. As this thesis aims to answer research questions considered by the primary researcher to be highly worthy for both science centres and participants, it has held my personal focus for its entire duration. This personal engagement, and engagement from co-authors and supervisors, has helped to ensure the quality of the studies. Issues related to personal motivation and bias in the studies are discussed below. As Miles and Huberman (1994) note, ethical issues arise concerning whether the benefits of the research correspond to the resources required. Arguably, the question of benefits is related to the question of worthiness. Therefore, the question is whether the research succeeded in answering the questions it was designed to answer. This may result in bias that influences the quality of the research project.

Bias: Discussing bias and objectivity, Miles and Huberman (1994) write that researchers' personalities will likely influence a study. Longino (1996) raises a related issue, noting two sets of virtues or values that guide research, one that is social and political and one that is cognitive. She argues that one cannot separate cognitive and non-cognitive sets of values. This argument implies that research will be biased by researchers' values and intentions. This project is partly funded by the venue where the study is situated and partly the Research Council of Norway (Research Council of Norway, 50% and VilVite, 50%) and the goal, as discussed, is to develop methods to harness the educational potential of exhibitions. This implies that the science centre expects a particular result from the project and considers it worthy of investment. Arguably, this expectation can result in bias. Miles and Huberman (1994) argue that researchers should address this issue of bias by being explicit about the context and condition of a study. External reliability may be closely linked to trustworthiness. We have addressed trustworthiness by presenting the first author of the papers as an employee of the venue in question and detailing the relevant methodology of the study. An interesting perspective in this discussion is provided by Longino (1996) who argues that

> *"We should worry more about the concealing of political agendas behind the mantle of scientific neutrality than about the consequences of abandoning the illusion of neutral arbiters of our cognitive practices."* (p.55)

Ultimately, the question concerning ethics and bias is: Have we presented the studies, including the researchers, in a way that discloses inevitable bias and avoids concealing political agendas? We argue that we have, both in the thesis and individual papers, within the limitations of academic papers.

4. Theoretical Framework

This chapter presents how theory on learning has influenced the development of frameworks for the design and evaluation of educational material presented in this thesis.

4.1 Practical work and exploring interactive science exhibitions

Interactive science exhibitions are designed with the purpose of facilitating science learning. To this end, exhibit design aims to invite visitors to interact with science-related phenomena and objects. This design can be said to facilitate what Millar (2004) denotes as

> *"practical work by defining it as [...] any teaching and learning activity which involves at some point the students in observing or manipulating real objects and materials (p. 2)."*

The concept of *practical work* can be used as a guide to find similarities between learning activities in the context of science exhibitions and the context of, for example, laboratory work in school, and as such provide guidance for transferring knowledge from learning in a school context to an exhibition context.

I first describe practical work as developed for a school context. Millar (2004) states that the role of practical work is to construct links between the domain of what can be observed and the domain of ideas. Tiberghien (2000) uses a similar terminology, describing practical work as a *modelling activity* which involves an interplay between observations within the world of objects and events on the one hand, and the theoretical interpretations, predictions, or explanations which belong to the world of theories and models on the other. Tiberghien (2000) emphasizes that for the activity to result in construction of links between the world of observables and the world of theory and models, the activity must be adapted to learners' prior knowledge. She also emphasizes the significance of taking into account mental and affective aspects that influence student engagement. Millar (2004) builds on this notion, stating that the structure of a task must scaffold students' thinking. In reviews, Hofstein and Lunetta (1982; 2004) point to practical work in the unique setting of school laboratories that facilitate cooperation and peer discussion in small groups.

As reported in Hauan & Kolstø (2014), several researchers have discussed how exhibition-related activities can result in science learning. The design of exhibit related tasks, including text and the assignment of roles, can facilitate understanding of the world of scientific models through, for example, the reading of texts that contain scientific concepts, recording observations, and content-related talks between students, or with teachers or staff (Bamberger & Tal, 2007; DeWitt & Hohenstein, 2010, a; DeWitt & Hohenstein, 2010, b; Stavrova & Urhahne, 2010; Yatani, Onuma, Sugimoto & Kusunoki, 2004). Exhibits can facilitate exploratory observation of phenomena and objects (Anderson, Lucas, Ginns & Dierking, 2000; DeWitt & Osborne, 2010; Falcão et al., 2004; Rix & McSorley, 1999). Well-designed exhibits facilitate linking to prior experiences and can facilitate conceptual development (Anderson et al., 2000; Gilbert & Priest, 1997). However, misconceptions resulting from prior experiences can also result in new or confirmed misconceptions (Anderson et al., 2000). Work in exhibitions typically involves group work and this is found to enable cooperation between students, an action which has the potential to support learning (Bamberger & Tal, 2007; DeWitt & Hohenstein, 2010, b). The structure of designed tasks can enhance students' engagement (Bamberger & Tal, 2007; DeWitt & Hohenstein, 2010; 2010, b; Jarvis & Pell, 2005). Such tasks can facilitate thinking, for example, by promoting the refusal or denial of hypotheses (Rix & McSorley, 1999).

Studies related to exhibitions inform us that work in interactive science exhibitions can potentially facilitate activities that correspond to activities involved in, what Millar (2004) describes as, *practical work,* and for which Tiberghien (2000) provides design guidance. However, these studies also note challenges in exploiting this potential: student focus may be reduced; they can be overwhelmed by impressions or a desire to see all aspects of an exhibit; and they may lack sufficient prior information which may lead to various emotional states, such as anxiety (Anderson & Lucas, 1997; Jarvis & Pell, 2005; Kubota & Olstad, 1991). Complex exhibition design may lead to misinterpretations or hinder intended observations (Falcão et al., 2004; Henriksen & Jorde, 2001). Labels are often not read by young visitors (Borun & Miller, 1980). Interaction with exhibits may confirm or strengthen previous misconceptions (Anderson et al., 2000).

Practical work (Millar, 2004) involves the characteristics of fruitful task design. We are informed by exhibition-related studies about the potentials and challenges of *practical work* in an exhibition context. What is needed is guidance in designing beneficial activities for an interactive science exhibition. The following sections present findings in literature on learning that are related to these activities and discuss how this literature has guided the development of frameworks for the design and evaluation of the work presented in this thesis.

4.2 Learning activities that suports progress towards conceptual understanding.

An interactive science exhibition is a setting which presents objects and phenomena, is well-suited for group work, and where a visit is considered enjoyable by many students (Rennie & McClafferty, 1996). Based on previous studies and the nature of an interactive exhibition, we argue that such exhibitions are settings that have the potential to facilitate *practical work* which results in linking observable aspects and ideas. Put simply, practical work supports understanding of scientific concepts by letting students experience phenomena and linking these phenomena to corresponding scientific terms and descriptions on labels or handed-out material. As we learned from writing Hauan & Kolstø (2014), research on the potential of exhibitions has inspired researchers (e.g. Anderson et al., 2000; DeWitt & Osborne, 2007) to be guided by a range of theories and thinkers within the field of education and teaching. Theories focused on language, examining how development and the use of language influences learners' development of conceptual understanding, have been developed by, among others, Vygotsky (1986) and Lemke (1990). The influence that observing real objects and phenomena through multiple senses has on understanding science concepts is emphasised by, for example, Dewey (1997) and Millar (2004). Theories on learning from a cognitive development perspective, involving the active construction of knowledge by individuals, have been developed by Piaget (1964) and Ausubel et al. (1978), to name a few. Others have focused on how learning is shaped by human interaction within a socio-cultural context, for example, Wertsch (1991) and Wells (1999). Dewey (1910; 1997; 2011) can be considered to have a holistic perspective on learning which involves both a focus on learners' personal construction of knowledge, resulting from thinking based on input from interaction with the physical world, and a focus on how learning is influenced by the social environment learners interact within. Our efforts to identify activities that exploit the potential that interactive exhibits have for *practical work* (Millar, 2004) are guided by the work of theorists such as those discussed and the concept of *modelling activity* as described by Tiberghien (2000).

We have identified a set of activities that are significant for science learning and characteristics of tasks that make these activities effective. These activities and their characteristics were identified and determined to be implementable in an exhibition context, guided by theory within education and teaching, and by relating literature on practical work in schools to reports from studies on science exhibitions. These identified activities are: *Using Science Language,* reading or listening to words that label phenomenon or objects; *Multisensory Observation,* the observation of scientific phenomenon or objects; *Linking of experiences,* relating newly presented knowledge to existing cognitive structures; and *Working together,* students working with peers in small groups and teacher involvement. The given tasks should facilitate *Reflective exploration,* where reflections involve previously listed activities, and *Personal engagement,* where the structure aims to support individual students in a way that creates generative mental activities.

4.2.1 Using Science Language

Vygotsky's (1986) perspective on the development of humans as persons is that we are shaped by the culture in which we live and communicate. For him, language is considered the most influential tool of communication and this tool is the driving force in the process towards conceptual understanding. To clarify his view, he compares his ideas with Piaget's. In contrast to Piaget, who considers learning, according to Vygotsky (1986), as a process of incorporating ready-made conceptual understanding into a learner's cognitive structure, Vygotsky considers development towards conceptual understandings as a negotiating process which involves verbal dialogue with others. The significance of language is, however, also acknowledged by Piaget (1935; 1965), who recognises that dialogue between teacher and students, for example, or between students, has the potential to enhance and create awareness of understanding through verbalization. But in contrast to Vygotsky, the social use of language through communication is not considered by Piaget as crucial for the development of conceptual understanding. Dewey's (2011) sees language more as an integrated aspect of the mental process of thinking, necessary for an experience to result in conceptual understanding of an idea or theory that needs to be generated to facilitate further thinking and communication. These three thinkers see language as a key factor in the process of learning and as that which enables us to communicate knowledge. Their differences lay in their views of its significance in the process of conceptual understanding. While Vygotsky views it as the decisive tool, Piaget and Dewey consider language as one of several tools involved in the process.

Wellington and Osborne (2001) state, with reference to Vygotsky, that language development and conceptual development are continuous processes. The experience of dialogue with words used in science can support the process of conceptually understanding the meaning of these words. Lemke (1990) puts it simply:

> *"How do we learn to talk science? We learn this language in much the same way as we learn any other: by speaking it with those who have already mastered it [...]" (p.1).*

Characterizing words in science learning, Wellington and Osborne (2001) states that "*concept words*" (p. 21) are the largest category and that they cannot be understood in isolation. Concept words can be characterized as "*part of a network of other words, all related together, often in vertical structure"* (p.21). This description sheds light on the meaning of *conceptual understanding,* emphasizing the fact that one needs to understand the meaning of concept words in a given conceptual context.

Lemke (1990) points to dualism in dialogues. A dialogue involves an activity which follows a structure of interaction by using words. The activity of combining words into meaningful structures is called a "*thematic pattern*" (Lemke, 1990, p.13). The activity of combining words into thematic patterns involves the mental activity often called thinking. Mercer (2000) points to the inherent relationship between thinking and the use of language. He emphasizes the role of spoken language and its ability, as a tool, to enable people to share ideas and think together while sharing an experience. Mercer reminds us that participants' experiences of such joint experiences are also influenced by individuals' prior experiences. The talk category "*Exploratory talk*" (Mercer, 2000, p.98) is categorized by participants exposing thoughts resulting from joint experiences and their prior experiences, as well as by the constructive responses of others to these thoughts. Such open sharing of thoughts and ideas has the potential to lead to new and shared knowledge.

For our design framework, we were guided by advice given by Abrahams and Millar (2008) to facilitate students' encounters with the scientific ideas described by scientific language. The authors advise that the ideas should be *in play* during the practical activity. Practical ways to accomplish this are suggested by Wellington and Osborne (2001), who advise that students should be given opportunities to discuss science as part of hands-on experiments. They provide practical examples for how to structure such activities, involving concept words, for example, concept cartoons (Keogh & Naylor, 1999), or "*Collaborative concept mapping*" (p.84). Mercer (1996) argues that there is a need to carefully structure activities if the goal is exploratory talk. This is supported by an empirical study wherein Mercer, Wegerif, and Dawes

(1999) designed such activities and found that such talk can have a positive influence on the learning of 9–10-year-old students.

4.2.2 Multisensory Observation

Vygotsky (1978) recognized that practical activity plays a role in children's development, but viewed it as a subordinate process. Later, Zinchenko, a student of Vygotsky, criticized this view and claimed that practical activity mediates between the mind and reality (according to A. Kozulin (Vygotsky, 1986)). Piaget (1935; 1965) emphasized the significance of presenting learners with activities that involve physical experiences. He viewed experience observing phenomena as the primary source of knowledge, rather than experiences solely involving language. In agreement with Zinchenko, Dewey (2011) draws our attention to the whole body, with its senses and muscles, and reminds us that these are the interfaces between the real world and the mind. He reminds us that knowledge is not automatically achieved by sensing phenomena and objects, rather one has to be conscious of sensory observations for them to be involved in the mental activity of gaining knowledge (Dewey, 2011). As with differences in views on the role of language, these developmental psychologists differ on the role experience and sensing have in the processes of science learning. Arguably, however, they all acknowledge that observation of reality is necessary for gaining knowledge of reality.

In agreement with Dewey's perspective on sensing, Beard and Wilson (2013) note that our senses are how our mind interacts with the world, with nature, artefacts, and humans, and they consider sensory experiences as the raw material of the process of learning. Tokuhama-Espinoa (2011) discusses results from experiments in neuroscience, relating these results to psychology and pedagogy, noting that the learning of life skills, including academic skills, requires sensory input. From a biological perspective, Sousa (2011) states that the brain communicates with the world through the senses and this sensing directly influences learning taking place in the brain's network of neurons. Interestingly, researchers (e.g. Black, Segal, Vitale &

Fadjo, 2012) working with digital learning material draw from the influence that senses have on learning. They argue for simulating observation of real objects or phenomena through, for example, a "*force feedback joystick*" (Black et al., 2012, p.200). As discussed, sensing is essential for learning. However, as Bransford, Brown, and Cocking (2000) remind us, observations by senses do not by themselves result in knowledge development in terms of conceptual understanding or generalization. Such development requires relating and reflecting upon observations in relation to theories or models within a given field.

The observation of phenomena and objects is a key element for our framework, and, in agreement with the literature discussed, we aim to facilitate observation through multiple senses. The exhibits in interactive exhibitions are typically designed to facilitate the multisensory observation of specific phenomena or objects (Gilbert & Stocklmayer, 2001). However, studies have shown that students may not observe as intended or misinterpret their observations (e.g. Anderson et al., 2000; Henriksen & Jorde, 2001). The aim of educational material is therefore to guide students' observations. Additional advice we follow, provided by Falcão et al. (2004), is to present related concepts within a specific field using a set of exhibits that facilitate observation of different objects and phenomena within this field, guiding students in seeing how these concepts can be meaningfully related (Ausubel et al., 1978).

4.2.3 Linking Experiences

Over the years, a number of theorists have paid attention to the way in which experiences may link together in the learning process. For instance, Dewey (1997) considers education as a process of growth where an experience is influenced by previous experiences and influences the nature of future experiences. He reminds educators that every experience is a moving force and calls for awareness of its potential effect on both the outcome of, and motivation for, learning. What an individual learns through one experience alters awareness of potential learning possibilities in new experiences and can guide future searches for experiences (Dewey, 1997). With his concept of a *zone of proximal development,* Vygotsky

(1986) provides a framework for how knowledge gained from previous experiences should be used as a resource in guiding learners' development. Vygotsky (1986) advises that processes towards new knowledge should start with the identification of an individual's existing knowledge as a starting point for guiding development towards new, gained knowledge. With a cognitive perspective, Piaget (1964) contributes to understandings of the influence of knowledge gained from previous experiences by developing a model that describes the development of conceptual structures. He considers learning as cognitive development, where existing structures are changed to accommodate new conceptual understandings or new conceptual understanding are assimilated into existing cognitive structures and schemas (Piaget, 1958; 1975). Ausubel et al. (1978) develops a model similar to Piaget's (Gruber & Voneche, 1977), however, where Piaget uses schemas as an analogy to describe a model of cognitive structures, Ausubel uses networks. Piaget describes learning as a shift from not knowing to knowing, while Ausubel's network model allows for a more dynamic description of how cognitive structures are shaped by new experiences. It describes learning as a process where networks grow by accommodating new knowledge, strengthen by creating new links between concepts or clusters of concepts, and develop misconceptions caused by arbitrary cognitive structures. A part of Ausubel's work is a description of the rationale and significance of preparing students for forthcoming educational experiences. He uses the term *advance organizer* to describe preparations that facilitate links between existing knowledge and new concepts (Ausubel et al., 1978). A summary of the views of developmental psychologists on the influence of pre-existing knowledge from prior experiences is included in an extensive review by Bransford et al. (2000) who state that the "*contemporary view of learning is that people construct new knowledge and understandings based on what they already know and believe*" (p.10).

With their review, Bransford et al. (2000) remind us that cognitive development is a continuous process which is shaped not only by experiences in school but also during leisure time. Bransford et al. (2000) argue that existing ideas resulting from both experiences during school and leisure time need to be taken into account for an educational sequence to result in the intended learning outcome. They argue that students need guidance to draw from their experiences during leisure time for learning. Ignoring this aspect may limit learning outcomes or risk linking experiences to prior misconceptions, confirming incorrect ideas or resulting in new misconceptions. Bransford et al. (2000) discuss methods for approaching this challenge such as "*bridging*" (p.179). This involves beginning from students' correct understandings. Osman and Hannafin (1994) argue for taking students' "*concept-relevant knowledge*" (p.5) (distinguished from deep knowledge) as a starting point. Such knowledge is often knowledge from everyday experiences. They argue that bridging can be achieved through questions that activate concept-relevant knowledge. This argument is supported by an empirical study with 10th grade students that suggests using orienting questions that aim to activate concept-relevant knowledge can help students to integrate new knowledge into their cognitive structures (Osman and Hannafin, 1994).

With our design framework, we take on the responsibility, as noted by Dewey (1997), of facilitating links between the educational experiences we provide and the previous and future experiences of students. To do so, it is necessary to investigate topics students have encountered or will encounter in school related to a given topic along with concept-relevant knowledge gained from everyday experiences. To facilitate connections to school experiences, school text books and teachers can be consulted. To activate previously acquired concept-relevant knowledge, illustrations can be used that show how relevant phenomena and objects are present in everyday scenarios.

4.2.4 Working together

Several researchers argue that cooperation can potentially support learning. Dewey (1997) states that experiences of educational quality should involve social activities through which all learners can contribute. Fruitful contributions from cooperating members involve interacting by sharing and responding to ideas and understandings (Mercer, 2000). Successful contribution also means allowing social control to be shared within the group and focusing on work with given tasks (Dewey, 1997). As described, Vygotsky (1986) suggests that contribution in a social setting can support the development of conceptual understanding by facilitating a negotiating process which involves dialogue with others. This negotiation involves the mutual development of the existing understanding of learners and understandings to be learned and incorporated. Vygotsky (1978; 1986) uses the term *tools* to describe mediational means for this negotiating process. In accord with Vygotsky, Wertsch (1991), discussing human development, states that people are shaped by the actions they are part of and actions are shaped by the mediational means involved. With reference to Vygotsky, he uses the term *tool kit* of mediational means to designate all means of communication involved in an action, including individual means, such as mnemonic techniques, and social means, such as a work of art. The perspective that Wertsch (1991) presents suggests that humans should not be considered as individual units but as individuals in a social context which shapes the individual. With reference to Vygotsky, Wells (1999) also uses the metaphor of a tool, suggesting language is the *tool of tools*. He points to language as a tool that allows for the presentation of individuals' inner thoughts to others which then allows for feedback. This feedback facilitates an individual's mental activity, inner dialogue, where feedback interplays with existing ideas. Interestingly, Wells (1999) argues that learning, in terms of using knowledge gained in unfamiliar situations, is achieved in joint activities where understanding is shared and responded to. Such arguments and research affirm the importance of letting students work together in groups and that these are carefully organized and facilitated.

Wells (1999) considers practical work to have the potential to create joint activities that can result in collaborative knowledge building. However, he warns that the equipment and practicalities of practical work may hinder students' understanding of the content and goals of an activity. With reference to Lave and Wenger (1991), Wells (1999) argues that all participants can get an educational outcome from an activity as long as "[…] *they are able to make sense of what is going on because they obtain a general grasp of the goal of the activity from other cues in the situation*" (p. 219). This, however, according to Wells, demands a physical and social learning environment that invites all to participate by expressing their thoughts and ideas. This is congruent with Dewey's (1997) call for educators to take on the responsibility of designing educational activities that provide participants the ability to contribute to a given task and influence how work is done. Relatedly, Joint Productive Activity (JPA) is proposed by Dalton and Tharp (2002) as a *standard* for designing activities that can result in collaborative knowledge building. The design of JPA activities involves facilitating group work where students are provided with the necessary time and resources that enable them to work together towards a common goal. Both Dewey (1997) and Dalton and Tharp (2002) emphasize the significance of teachers' roles in facilitating activities and their involvement in students' work. Teachers' roles are also highlighted by Hattie (2009), who, based on an extensive review of studies related to learning, concludes that the teacher is the single factor with the highest influence on students' learning. The literature presented above, together, highlights that working in groups can have a significant positive impact on learning if the nature of the task and the social climate results in the involvement of all participants and if sufficient resources are provided. Facilitating group work is also strongly supported in a review by Johnson, Johnson, and Stanne (2000), who conclude, based on studies of a wide range of cooperative learning methods, that *"[...] cooperative efforts result in higher individual achievement than do competitive or individualistic efforts"* (p. 12).

Arguably, exhibits in science centres are designed to reduce problems with equipment and the practicalities related to practical work which Wells (1999) describes. By designing educational material, we also aim to reduce these challenges. Through our design, we strive to facilitate, for all students within a group, participation via interaction with exhibits and text from handed-out materials. This is done through the sharing of task-related thinking and responses to thinking expressed by others. As such, the tasks function as a support for organizing the group. Teacher involvement is facilitated through a summarizing task which invites teachers to support students in their work.

4.2.5 Reflective exploration

Mental activity and its influence on learning is discussed by several theorists. Dewey (1910) uses the term *thinking* for the mental activity necessary for gaining new knowledge. He states that *"thinking, in short, must end as well as begin in the domain of concrete observations, if it is to be complete thinking"* (p.98). He follows this by specifying that concrete observations must be from interactions with real objects. And, for learning to be a process of growth, the observation has to be linked to prior experiences (Dewey, 1997). Dewey (1910) presents a five-step model that describes how exploration and reflection on a problem can lead to new knowledge. Dewey's views on thinking and learning are also discussed by several other researchers. For instance, Dewey's reflective process is articulated by Beard and Wilson (2013) as a three-step feedback process where a situation is explored, reflected on, and learned from. They further discuss and compare Dewey's description of the learning process with those presented by Lewin (1951) and Kolb (1971), and find that these descriptions also correspond to Dewey's. Kolb (1984) contributes to this discussion by stating that Piaget's (1935; 1965) description of a learning process is similar to Lewin's and Dewey's. Common to all of these descriptions is the involvement of thinking and feedback loops that potentially result in new knowledge.

In the following sections, we discuss two conditions that Dewey (1910) notes as requirements for a fruitful thinking process. First, he argues that *"[...] the mind should be sensitive to problems and skilled in methods of attack and solution"* (p. 79). A challenge we encounter with this condition is that one cannot assume that students have such skills. Therefore, material that is handed-out should guide students' explorations and work with given tasks by designing for what Hauan & Kolstø (2014) have designated *GEL* experiences. *Scaffolding,* as described by Wood, Bruner, and Ross (1976), is one example of a concept that can provide guidance for the design of guides.

Secondly, Dewey (1910) argues that for fruitful thinking to begin, individuals have to be emotionally engaged in problem-solving. According to Dewey (1910), this engagement has to come from within. Moreover, the problem should be identified by the learner. Intrinsic motivation has the potential to support learning, however, it can be challenging to design for its occurrence in all educational experiences. This challenge is related to the elicitation of personal engagement and is discussed later. Here we focus on individual differences. One such difference is how individuals enter a problem solving process that requires thinking. Thinking processes are often described as loops that have a defined starting point (e.g. Kolb, 1984), however, Honey and Mumford (1992) note that people are different and may enter an exploratory thinking loop at different stages. For example, some may begin with careful reflection, while others may begin by experimenting in an open-minded manner. All learners need, however, to complete the explorative thinking loop to gain a meaningful learning experience. A loop related to solving a task in an exhibition, for example, could begin with the physical exploration of the exhibit before reading texts which describe the task; or begin with reading and then a consideration of the required actions.

Our proposed design framework aims to create an embedded learning environment by incorporating the following elements: science texts, exhibits, students' prior experiences, and peers and teachers. In agreement with Dewey (1910; 1997; 2011), the framework strives for these elements to be resources for exploratory activities which involve the previously described learning activities: engaging with text that contains focal scientific concepts, multisensory observation of focal objects and phenomena, linking to prior experiences, and expressing thinking and responding to others expressed thinking. To accomplish this, material must both facilitate these activities and provide students with tasks that require thinking. Moreover, the task must support participation by all group members and should be open in a way that allows for different ways of contributing to solving the given tasks.

4.2.6 Personal engagement

The affective dimension of learning has been discussed by several developmental psychologists. The conflict which results from a lack of understanding and an inherent need to achieve equilibrium is considered by Piaget (1964) to be the driving force behind both accommodation and assimilation, resulting in new conceptual understanding. Ausubel et al. (1978) states that "*Motivation […] is absolutely necessary for the sustained type of learning involved in mastering a given subject-matter discipline*" (p. 397). Ausubel is in accord with Dewey's (1910) view of personal engagement as a condition for fruitful reflective thinking, as discussed. These developmental psychologists represent a shift from seeing the learner as a passive recipient to see learning as a process where the individual learner is a primary, active agent. Building on this trajectory, Gardener (2006) does not view learning as progressing in a broadly uniform way for all individuals. Gardner's theory of Multiple Intelligences suggests that there are individual differences in learners' configurations of abilities. Although Gardener's theories have received criticism, findings from empirical studies by Cluck and Hess (2003), and by Haley (2004), suggest that these sorts of individual differences also make motivation an idiosyncratic feature. Gardner (2006) argues that the application of what he designates "*Multiple Entry Points to Understanding*" (p.138) can guide leveraging of differences in learners' abilities.

The term *learner-centred* is used by Bransford et al. (2000) to describe learning environments "*that pay attention to* [learners'] *knowledge, skills, attitudes, and beliefs*" (p. 133). In particular, Bransford et al. (2000) discuss the importance of encouraging personal engagement by attending to differences in learners' individual prior knowledge resulting from everyday experiences and cultural backgrounds. Sousa (2011) adds *interests* to the factors that shape a personal learning environment and can facilitate personal engagement. The elements of prior knowledge, skills, attitudes, beliefs, learning-style, and interest, are all related to *intrinsic motivation* (Falk & Dierking, 2000; Sousa, 2011). Attempting to accommodate learners' intrinsic motivations through the design of tasks is demanding because intrinsic motivation is idiosyncratic. A seemingly more obtainable goal is facilitating personal engagement. Design elements that could encourage personal engagement are discussed by several researchers: linking to prior knowledge (e.g. Bransford et al., 2000; Ausubel, 1978);

proper level of difficulty, structure, setting clear goals, and providing feedback (e.g. Csikszentmihalyi, 1991; Wood, Bruner & Ross, 1976); a social environment that invites all ideas and propositions (e.g. Lave & Wenger, 1991; Wells 1999), and incorporates multiple entry points (Gardner 2006). The brain is constantly in search of novel inputs (Sousa, 2011; Tokuhama-Espinoa, 2011), and such input creates engagement. Sousa (2011) suggests methods to incorporate novelty into task design, such as the use of humour, movement, multisensory instruction, and quizzes or games.

Interactive science exhibitions have the potential to generate a sense of novelty, interest, enthusiasm, motivation, and eagerness to learn (Falk & Dierking, 2000; Pedretti, 2002; Ramey-Gassert, Walberg, & Walberg, 1994). In our framework, which includes the exploration of interactive exhibits, we aim to use and enhance this potential for creating personal engagement by including the elements presented above. Materials we created were designed to: generate enthusiasm, link to prior knowledge, provide a structure that guides students with tasks that they can master and receive feedback on, invite students in groups to engage with tasks in ways they prefer, and to incorporate *entry points to understanding* (Gardner, 2006) when appropriate for a given task and structure.

4.3 Design of educational experiences in interactive science exhibitions

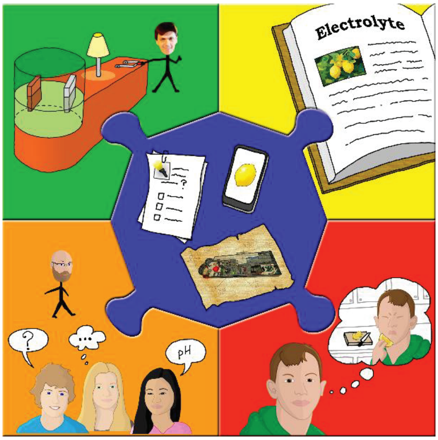
Science museums and other venues for science communication are considered by several researchers to have the potential to be engaging learning environments. Examples of such venues are pioneer centres (Piaget, 1935 & 1965), science centres (Gardner, 2006), and museums in general (Csikszentmihalyi & Hermanson, 1995). *Practical work* could potentially benefit from the context of an interactive science exhibition. Our design framework aims to make the most of this potential by facilitating activities that involve elements described above: *using science language, multisensory observation, linking of experiences,* and *working together*. We would also argue that designs for educational experiences should also embed the following resources: exhibits, meaningful scientific text with concept words relevant to curricula, students' prior/everyday/concept-relevant knowledge, and groups of students including teachers. A proposed design framework for embedding these resources is named an ELE, which is presented in chapter five. Embedding resources in a learning environment also involves designing for GEL (Hauan & Kolstø, 2014). More specifically, it requires scaffolding students' thinking and engaging them in reflective exploration, as discussed. The principles of GEL and ELE are applied in design of interventions presented in Hauan, DeWitt, and Kolstø (2015), and Hauan and Hällman (submitted 2016).

4.4 Evaluation of educational experiences in interactive science exhibitions

Concept learning is a continuous process (Ausubel et al., 1978; Dewey, 1997) and to conduct studies that measure changes in conceptual understanding resulting from a specific experience is demanding. As assimilation of new knowledge depends on existing cognitive structures, both pre- and post-event measurements would need to be conducted. This raises a dilemma, namely, that measuring prior knowledge might simultaneously activate this prior knowledge (Ausubel et al., 1978) and thereby influence the outcome of an educational experience and in turn the measured outcome. Additionally, Sousa (2011) notes the need to wait for at least 24 hours before information transfer to long term memory storage can be tested. This implies the need for well-designed and lengthy studies with control groups.

The challenge of measuring learning outcomes with quantitative studies is confirmed by reviews of studies of laboratory work in schools by Hofstein and Lunetta (1982; 2004). They report that they have not found studies which have measured specific conceptual learning outcomes from specific interventions categorized as *practical work*. The challenge of measuring the outcome of practical work in school is also discussed in a review by Millar (2010, in Osborne & Dillon). In science centres and other venues for science communication, it is also likely difficult to measure the outcomes of practical work (Hauan & Kolstø, 2014). One possible way to deal with this challenge is to evaluate the quality of an educational experience from the perspective of process (Rennie, Feher, Dierking & Falk, 2003). Hauan and Kolstø (2014) argue for developing such methods to evaluate "*the effectiveness of educational activities by studying the presence and quality of the learning processes visitors are engaged in*" (p. 1). One way to do this is to base evaluation on student behaviours resulting from use of educational material handed-out to the students. A study by Hauan, DeWitt, and Kolstø (2015) proposes a framework for conducting such evaluations. The proposed evaluation method is applied and further developed in Hauan and Hällman (sub. 2016), where it is used in a comparative study of designs of handed-out material. This method involves looking for behaviours which reflect *Multi-Modal Discussions* and relating identified behaviours to deep engagement and ongoing learning and engagement in the learning environment. This is then discussed in connection to the potential for *Preparation for Future Learning* (Bransford & Schwartz, 1999) and how interventions influenced group dynamics and teacher engagement.

5. Proposing a Framework for Designing Embedded Learning Environments

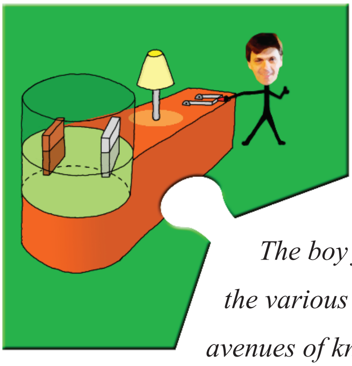


This chapter further elaborates a concept we have designated as an Embedded Learning Environment (ELE) and discusses it from a perspective of design and evaluation. ELE represents a synthesis of what we have learned from this PhD project and can hopefully be included in discussions of how to use interactive exhibitions as tools for engaging students in educational activities that lead to deeper understandings of scientific concepts.

The title of the first paper of this PhD project begins with the words "*Exhibitions as learning environments*" (Hauan & Kolstø, 2014). The term Learning Environment (LE) can be described as "*the diverse physical locations, contexts, and cultures in which students learn*" (http://edglossary.org/learning-environment). This concise description points to the complexity of the term, suggesting it involves more than elements within the scope of exhibition design. The Contextual Model of Learning (Falk & Dierking, 2000) describes museums and similar venues as LEs shaped by *personal context*, of individual visitors, the *sociocultural context*, influenced by visitors' companions, and *physical context*, prepared for the visitors. Several researchers have addressed the design of LE from a school-related perspective. Bransford, Brown, and Cocking (2000) emphasize paying attention to what the learners bring with them, fostering transferability by being knowledge-centred and focusing on understanding rather than remembering facts, facilitating formative assessment by making students thinking visible and self-assessment to help metacognition, and openness in terms of input from communities and generating products for the community. Choi and Hannafin (1995) argue that LE design should be based on real-life contexts to facilitate situated cognition. They emphasize that such contexts must establish linkages with prior experience and thereby empower learners to use skills they have previously acquired. Moreover, the physical setting and tasks should facilitate social interaction. The design of ELEs described in this thesis entails designing educational material which uses characteristics of elements in LEs, namely exhibits, texts related to scientific subject matter, individual students, their peers, and teachers. In agreement with the literature presented above, ELE are discussed from a design perspective. The aim is to provide guidelines for embedding elements, active engagement in the LE, guided exploration, and connections to real-life settings.

5.1 Creating an Embedded Learning Environment.

Elements that are beyond designers' control generate challenges for designing an ELE (Hauan & Kolstø, 2014). Exhibits are often designed by others, the content of subject matter related texts are defined by a curriculum, we do not control who is coming, nor can we control who visitors are coming with. However, what we can control is the design of the educational material which is offered to visitors to guide them in their experiences. To embed the elements of an LE, we need to have knowledge about these elements. To guide the search for knowledge about elements and how to embed them, we present knowledge gained from analytic and empirical research and lessons learned from the three papers of the current PhD project.



5.1.1 Embedding exhibits presenting scientific phenomena

> *"[...] senses and muscles are [...] external inlets and outlets of the mind.*
>
> *The boy flying a kite has to keep his eye on the kite, and has to note the various pressures of the string on his hand. His senses are avenues of knowledge not because external facts are "conveyed" to the brain, but because they are used in doing something with a purpose.* (Dewey, 2011 p.79)

In his paper "*The role of practical work in teaching and learning in science",* Millar (2004) emphasizes that practical work is essential for science learning. He further specifies that practical work involves observing or manipulating real objects and materials. Similarly, Dewey (2011) describes the function of embodied experiences involving observation and manipulation by stating that *"[...] senses and muscles are [...] external inlets and outlets of the mind*" (p. 79). One of the four principal elements in the conceptual framework for intervention design presented by Hauan, DeWitt, and Kolstø (2015) implies that exhibits are designed to support understandings of scientific concepts by letting students experience phenomena and their descriptions. A crucial question is then: do students observe phenomena and interpret their observations as intended by the exhibit designer?

Our literature review (Hauan & Kolstø, 2014) found few studies on the influence of exhibit design on students' learning and they provided limited guidance for the design of exhibit-related tasks. However, the review did result in some clues for the design process.

First, complex exhibits designed to communicate an extensive subject can be misunderstood (Henriksen & Jorde, 2001). Solutions to this challenge can include a number of exhibits which present different elements of the subject matter (Falcão et al., 2004). This advice was encouraging and supported our thinking regarding the inclusion of a selection of typical science centre exhibits into an educational path, using these exhibits as focus elements in a larger story.

Moreover, students' interactions with exhibits may result in misconceptions, especially if exhibits depend on users having a sufficient degree of background knowledge (Anderson et al., 2000; Henriksen & Jorde, 2001, Rix & McSorley, 1999). Misconceptions can be generated if students misunderstand what the exhibit is designed to convey, or if students' prior misconceptions are confirmed from misinterpretations caused by these prior misconceptions.

Clues from the literature review (Hauan & Kolstø, 2014) also guided us in our dialogue with students whom we observed and interviewed ad-hoc, as well as those who participated in a pilot study as part of the preparation of the design of task-sheets, described in the second paper (Hauan et al, 2015). From these initial studies, we learned that students often do not see what the exhibit designer intended for them to see. What students were supposed to observe was often simply outside of their field of vision. This was caused by trivial physical reasons, such as user height (e.g. some students did not observe a bulb that was lit from a generator because it mainly shone upwards); or, interaction design which resulted in exhibit-generated responses which caught user attention and narrowed focus (e.g. observation in a hydro-power exhibit was drawn towards a screen with real-time presentation of data and not the water level in a reservoir or water flowing through a turbine). The initial studies also confirmed that students in this age group have prior misconceptions that can be confirmed by exhibit interactions (e.g. that red and white coloured magnets in a generator were batteries as they made a light shine). We also found that phenomena presented in an exhibit can be misunderstood (e. g. that the hydropower turbine draws water out of the nozzles).

These deviations from the intended observations, and misunderstandings and misconceptions described above, are addressed in the design of material handed out with the purpose of guiding students' exploration (in this text designated as *handouts*) and the "*Concept Flow Chart*" (CFC) (Hauan et al., 2015) in order to provide scaffolding (Wood, Bruner & Ross, 1976) by guiding students’ observations and result in perception of focal concepts in the instructions. Additionally, in agreement with concerns regarding potential misunderstanding of complex exhibits raised by Henriksen and Jorde (2001), we aimed to focus students’ observations on an exhibit which presented a complex story concerning different methods of capturing CO_2. We aimed to focus students’ observations on part of the story which was relevant to the overall story of the intervention. Avoiding potential misconceptions was addressed by inviting teachers to scaffold students during their work with the CFC and by providing formal assessments by checking the results. We found it expedient to customize exhibit-related tasks to different types of exhibits characteristics. For “*Planned Discovery*” (PD) (Humphrey & Gutwill, 2005) exhibits with no apparent misunderstandings or misconceptions, we used only one overarching question to scaffold students’ explorations. To avoid potential misunderstandings and generating or confirming misconceptions, we used a set of sub-questions to scaffold the exploration. To focus students’ observations during exploration of complex exhibits and avoid misunderstandings, we instructed students to solve a simplified assignment and use a camera to record their exploration. The CFC was also designed with the goal of presenting the overarching story with limited risk of misunderstandings or generation of misconceptions. The CFC was made with a magnet board and loose magnet tags, naming focal concepts. This intuitive and tactile interaction design of the CFC was used to enable students to focus on a task and cooperate by composing meaningful sentences.

Analyses of video recordings (Hauan et al., 2015) showed that student exploration was highly influenced by guidance provided by handouts and the CFC. This indicates that the design of tasks in the educational intervention provided scaffolding, as intended.

In the beginning of this section, we related practical work to observation and the manipulation of real objects, stating that such experiences can help students understand scientific concepts. Moreover, Hauan et al. (2015) draw on Watson (2010) who, based on empirical research, states that students can also be helped in preparation for future learning (Bransford & Schwartz, 1999) by observing people they know well and can identify with, as these people have observable embodied experiences. All exhibits provided sensory input through vision, but the interaction design of three different categories: "*Generator*", "*Wind Bike*" and "*Water Power*" also provided sensory input through physical movement. "*Solar Plane*" provided visual responses from a real object, whereas the visual response from physical interaction with "*Carbon Catcher*" was generated by a simulator and presented on a screen. This design of the "*Carbon Catcher*" is an example of the challenges of designing for an interactive representation of phenomena that cannot be directly observed by senses or where bodily interactions are an impractical way to present the phenomena. Development of design principles for such phenomena in interactive exhibits in a fruitful way is of increasing importance. Fortunately, several researchers provide guidance on this issue, e.g. Noë and O'Regan (2002) discuss vision as an obvious but often overlooked sense that is actively used by the brain to generate sensorimotor inputs. Other researchers, e.g. Hannafin and Land (2000), point to simulations as a way to present phenomena and facilitate active exploration. We also believe that knowledge gained from "*active prolonged engagement*" (Humphrey & Gutwill, 2005) can provide guidance for the development of embodied experiences of phenomena that cannot be directly observed through sensory experiences. We were unsure whether "*Carbon Catcher*" fit our conceptual framework for intervention design (Hauan, DeWitt & Kolstø, 2015) but it was included because its interaction design agreed with guidelines provided by research presented in the area of embodied experiences.

Summary

There are some obstacles to using exhibits as tools to present scientific phenomena. This has been reported by research (Anderson et al. 2000; Henriksen & Jorde, 2001, Rix & McSorley, 1999), our own pilot study, and ad-hoc interviews. However, our investigations (Hauan, DeWitt & Kolstø, 2015; Hauan & Hällman, sub. 2016) indicate that thoughtful design of exhibit-related tasks can provide scaffolding which guides students in observations, thus supporting them in a process of conceptual understanding. When designing tasks, it is important to recall that tight scaffolding reduces students’ freedom and the openness of their explorations. The level of scaffolding should not therefore be tighter than necessary. The following paragraphs guide the design of exhibit-related tasks.

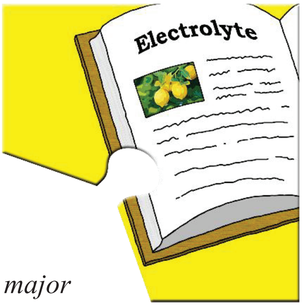
Select a set of exhibits that present phenomena relevant for the subject matter you want the educational path to address. The number of exhibits determines the number of students in each group. Observe and interview students in target grades while exploring the selected exhibits. Probe to clarify the following:

- Do they observe what you intend them to observe? If not, why?
- What words do they use when they describe their observations?
- How do they explain the exhibit-generated response to their manipulations?
- What is their prior knowledge of subjects presented in the exhibits? Do their descriptions reveal prior misconceptions or misunderstandings?
- Are they able to relate the presented phenomena to their everyday life?

When designing tasks, remember that the scaffolding should guide students’ exploration. It is not a set of instructions for the exhibit.

Designs for active engagement with the learning environment and meaningful learning, as well as how we have addressed what we revealed through initial observations and interviews with students, are discussed later in this thesis.

Exhibits as learning materials, especially as tools to provide the development of embodied experiences of phenomena that cannot be directly observed by senses, are and will continue to be a significant area for future research.



5.1.2 Embedding text with words that name scientific concepts

> *Learning the language of science is a major part (if not the major part) of science education. Every science lesson is a language lesson*
> (Wellington & Osborne, 2001, p. 2)

As discussed by Vygotsky (1987), as well as Wellington and Osborne (2001), language is a tool we use to acquire and communicate knowledge. Novak and Gowin (1984) present learning and knowing as different, stating "*learning is personal and idiosyncratic; knowing is public and shared*" (p. 5). Thinking is the active mental activity required for learning. Ausubel et al. (1978) emphasise the role language has in this process, noting "*language [...] plays an integral and operative (process) role in thinking rather than merely a communicative role*" (p. 40). These statements suggest that language can be seen not only as something external we encounter when we read text, listen to speech, or express ourselves, but part of an internal mental process. Meaningful text we encounter or express can be defined as consisting of concepts and linking words (Ausubel et, al., 1978; Novak and Gowin, 1984; Sutton, 1992). This draws attention to the significance of understanding the meaning of concepts recognized by the professional and social environments we communicate in. This is what constitutes concept learning.

When we discuss scientific concepts, we can see words as labels that name an object or phenomena. Conceptual learning within science can therefore simply be seen as acquiring an understanding of the meaning of words used in a scientific context. These words are what we use to describe the world through a modelling approach. Science concerns developing theoretical models to describe observable objects and phenomena or predict events. Tiberghien (2000) writes that the

> *acquisition of science understanding (conceptual, methodological and/or practical) requires the learner to construct links between the worlds of objects/events and theory/model.* (p. 31)

The role of practical work, according to Millar (2004), is to support conceptual understanding by helping students construct links between worlds of knowledge, as described by Tiberghien (2000). Abrahams and Millar (2008) argue that such linking is facilitated by generating "*activities in which the students manipulate and observe real objects and material*" (p. 1945) and by having words that label observable phenomena "*'in play' during the practical activity*" (p. 1965).

In agreement with the literature above, we consider encounters with text, which holds words that name observed objects and phenomena, essential for the learning of scientific concepts. The question is whether the text provided is noticed and used.

The review by Hauan and Kolstø (2014) presents several examples of the productive use of text. Kisiel (2003; 2007) reports that most teacher-made worksheets encourage reading and copying label texts. Visits can result in writing notes which are intended for future discussions (DeWitt & Osborne, 2007). Henriksen and Jorde (2001) found that students' writing style became more scientific when taking notes to be discussed in post-visit activities. Text presented through audio-guides can guide exhibit exploration and inform visitors about related scientific content (Heard, Divall & Johnson, 2000; Hsi, 2003). Text can also be presented as questions, intended to result in content-related thinking (Mortensen & Smart, 2007; Stavrova & Urhahne, 2010; Yatani, et al., 2004; Yoon et al., 2012). These empirical studies discuss text-related activities that can support learning, however, challenges related to perception, understanding, and reflection are also reported. Misunderstanding can result from texts (Anderson et al., 2000; Henriksen & Jorde, 2001), worksheets can make the visit less enjoyable (Griffin & Symington, 1997; Rix & McSorley, 1999), and audio-guides may have negative impacts on learning (Heard et al., 2000), create a feeling of isolation, or restrict exploration (Hsi, 2003).

Inspired by research presented above, and from a search for relevant concepts in school text books, we drafted a set of tasks with colourful text and illustrations presented on sheets of paper. The drafts were then presented to a group of teachers in designated school grades. The teachers commented that the texts were too long and students could be confused by the sophisticated language and use of coloured text. Text was therefore simplified before used in Hauan et al. (2015). Dialogue with teachers also guided us in selecting concepts to include in the intervention.

Evaluation of the paper-based handouts, based on students' behaviour, generally found that words were presented for students either by reading or focused listening to others reading, and that the words were "in play" during exhibit exploration (Hauan et al., 2015). It was also found that all students joined and worked with the group while solving the CFC puzzle, which involved setting concepts into a meaningful whole.

The influence of the design of handouts on students' learning-related behaviour was tested by looking at behaviours resulting from different designs (Hauan & Hällman, sub. 2016). We found that the likelihood of a text being perceived was highly influenced by the design. Handouts for GEL (Hauan et al., 2015; Hauan & Kolstø, 2014) resulted in significantly more reading or listening than the *traditional worksheets*. *Open exploration* resulted in very few incidences of reading text presented by labels. Results also indicate that the way GEL is presented influences students' engagement with the text provided. Hauan and Hällman (sub. 2016) hypothesized that GEL presented with digital-pads, where the tasks are presented with a number of windows, made engagement more complicated and thus required user instruction prior to the visit.

Summary

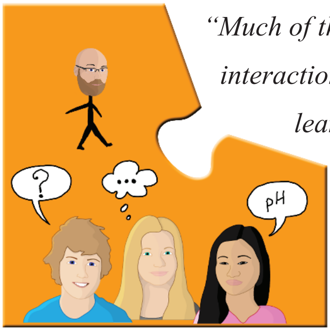
A key issue in science is the generation of models used to describe what we observe in the real world. Conceptual understandings within science involve a scientifically recognised understanding of words that are used in models to name objects and phenomena in the real world. Generating experiences that support science concept learning involves presenting objects or phenomena and words that name them. It is not sufficient to provide science-related text, as discussed. Interventions also need to provide guidance on how to relate to the provided text. We suggest, based on the research presented, that the following design-guidelines can support students in using the text available and help students' linking between what can be observed and scientific models.

- Hand-out material should include focal concept or guide students' reading of labels.
- Text should encourage exploration and observation.
- Scientific terms and concepts in the text should guide explorations and observations.
- Texts should be short, but keep in mind that they can be misunderstood. Present text sheets to teachers to receive feedback.
- Use appealing design for texts and illustrations but avoid confusing layouts. Ask for feedback from teachers.
- Concepts included should be part of school curricula so the intervention is relevant to the school. Consult national and local curricula, as well as textbooks. All schools in a region do not necessarily have the same textbooks so teachers should be consulted.

The layout of the paper-based task-sheets was inspired by the work of Kress and Leeuwen (1996). The task-sheets were quality controlled by presenting them to teachers. This design process informed the design for digital-pads. Findings by Hauan and Hällman (sub. 2016) indicate that readability can be impaired with a sophisticated digital design and that the use such material requires prior user instruction. Further research on the design of handouts with digital presentation is necessary.

Reading or listening to words while performing hands-on exploration does not necessarily lead to mental activities necessary for conceptual understanding. Methods to engage students in the required mental activity are discussed later in this thesis.

5.1.3 Embedding groups of students and their teachers.



"Much of the way humans make sense of the world is through social interaction with others, through distributed meaning-making. For learning, particularly learning in museums, is a fundamentally social experience" (Falk & Dierking, 2000, p. 38).

Visits to a science centre provide the opportunity for peers to work and learn together. Groups allow for the use of speech and physical expressions to communicate thoughts and receive feedback from others. This process is considered essential for learning by Vygotsky (1978; 1986). An interactive exhibit enables students to base their thoughts on the observation of phenomena and objects, thus meeting the demands of Dewey who writes, "*thinking in short, must end as well as begin in the domain of concrete observations, if it is to be complete thinking*" (Dewey, 1910, p.96) and practical work in groups facilitates sharing one's thinking, and proposing and getting feedback on one's developed understandings.

Tiberghien emphasizes that the learning environment includes both material and human resources. With reference to Vygotsky, Wertsch (1991) uses the term "*tool kit*" (p.93), which involves a similar view of a learning environment where both humans and educational material, such as exhibits, are considered psychological tools which can be employed in mediated action. Mercer (2000) discusses these perspectives in terms of the potential that working in a social context has to enable individuals to think together. He uses the term "*interthinking*" (p. 16) to describe coordinated activities where people use their minds to solve a shared task. Mercer's (2000) work focuses on language as a means of expressing thoughts, but he expands this notion, using dancing as an example of a coordinated activity. Wells (1999) not only sees working together as beneficial for the development of conceptual understanding, he emphasizes that understanding in terms of applying understanding to unfamiliar situations is achieved by developing this knowledge in joint activity.

Learning in a social context has also been studied by neuroscientists. Based on research within this field, Tokuhama-Espinosa (2010) indicates that shared information is reinforced in the brain and that learning is solidified when we work with others to resolve problems. Tokuhama-Espinosa (2010) also describes specific neurons called mirror-neurons which are activated when we observe other peoples' actions, providing the brain a similar experience to that observed. These neurons can be considered as a newly discovered communication tool that can help us to understand the rich and complicated nature of human interaction.

The positive impacts of cooperation as presented above appear to be confirmed by Johnson, Johnson, and Stanne (2000). In a comprehensive review, the researchers found that all tested forms of cooperation result in higher achievements than competitive or individual learning methods.

"*Teachers are the most powerful influences in learning*" (Hattie, 2009, p.238) and the significance of teachers in preparing, supporting, and assessing student work is emphasized and described by the concept of scaffolding (Wood, Bruner & Ross, 1976), as well different standards for pedagogy, as described by Dalton and Tharp (2000). This is an important reminder, as we follow a call from Kisiel (2003) to examine how interactive exhibits can enhance learning, for the design of self-guided, exploratory learning experiences (Hauan & Kolstø, 2014). Design guidelines for empowering teachers to take on their role as learning facilitators are provided by the first two principles of the "*Framework for Museum Practice*" (DeWitt & Osborne, 2007). These principles advise designers to cooperate with teachers and inform them of the structure and content of the intervention, as well as provide resources for pre- and post-visit activities.

As discussed in Hauan & Kolstø (2014), both Bamberger and Tal (2000), and Griffin and Symington (1997), found that students prefer to work in groups and consider cooperation to be productive for learning. We have not found published studies that have investigated the effect of student cooperation on learning outcomes in venues that communicate science. In his PhD thesis, Watson (2010) reports that in 6th grade students who watched peers using their body in physical interactions that could be clearly observed, there was an educational effect from the experience similar to that for the observed student. This result seems to confirm that mirror-neurons can result in similar effects on the brain of an observer as the person being observed (Tokuhama-Espinosa, 2010).

A study by Nyamupangedengu and Lelliott (2012) is informative with respect to teacher and staff involvement in student exploration of exhibitions and preparation by teachers for exhibits. Based on recordings of the discussions of 4th, 6th, and 7th grade students and their teachers and observations during a visit to a natural science museum, Nyamupangedengu and Lelliott (2012) advise that guidance provided by worksheets should be supported by guidance provided by teachers or staff members. They also emphasize that students should be given clear instructions regarding the agenda for the visit and completion of tasks.

The handout designed for Hauan et al. (2015) facilitated cooperation and interthinking by directly encouraging students to discuss and agree upon particular propositions and to agree upon which exhibit elements were relevant to be photographed. Hauan et al (2015) found that all students within the groups took part in solving joint work with the given tasks and that one or a few students in every group took on the role of organizer. Hauan and Hällman (sub. 2016) confirm that group members can and do take on the responsibility as organizer, however, how they do this and their success in doing so, particularly with regard to the inclusion of peers, depends on the design of the task-set. Handouts designed for GEL experiences

(Hauan & Kolstø, 2014) which guided students' actions, observations, group behaviour, and discussions resulted in a high degree of inclusion. Handouts designed like a traditional worksheet resulted in less inclusion than one that encouraged open, unstructured exploration of the focal exhibits. A hypothesis raised by Hauan and Hällman (sub. 2016) is that sophisticated digital guiding handouts can have negative effect on peer inclusion and that this can be ameliorated with pre-visit information.

During school trips, teachers are often preoccupied with logistics and other practicalities. This has been seen at several science centres, as reported by Tal, Bamberger, and Morag (2005). For this reason, teachers' involvement in students' work is therefore limited. We argue in agreement with Kisiel (2003), and DeWitt and Osborne (2007), that teachers' situations need to be considered and a role during the visit for teachers should be designed. The role of providing scaffolding while students complete the CFC puzzle (Hauan et al., 2015) was filled by teachers of all 14 classes in the study. This finding informs us that teachers can be involved in students' work and this can be arranged. Pre-visit information is also proposed by other researchers as important for enhancing the learning outcome (Anderson & Lucas, 1997; Jarvis & Pell 2005; Kubota & Olstad, 1991)

Summary

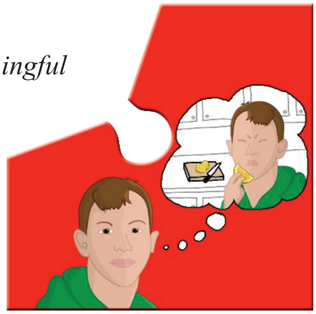
A group of students is a group of peers without formal authority and members within the group have relatively equal degrees of conceptual understanding. This provides the potential to construct and test individual understandings through their sharing and therefore understanding can be developed as a joint undertaking. Scaffolding for this process can be designed with material for self-guided, exploratory learning and by assigning a role to teachers. Our studies have also shown that scaffolding within groups can be facilitated by designing for students to take on the role of organizers. Such scaffolded, joint undertakings have the potential to support students' processes of conceptual understanding. To use the educational potential of students within a group and their teachers, designers should:

- Design tasks specifically for the involvement of all group members.
- Facilitate sharing of thinking.
- Avoid queuing by having the number of groups correspond to the number of exhibits or work stations. Six group members is viable, but fewer are recommended.
- Assign teachers with specific roles that support the provision of scaffolding during a visit. This can also increase the likelihood and quality of follow-up in the classroom.
- Generate videos or other forms of pre-visit, informative material that demonstrate to individuals how tasks are completed.

Our study of 11–13-year-old students showed that inclusion of all members can be facilitated with simple instructions. Methods to engage students to take on active roles in completing group assignments in other age groups, for example, would be of interest for further research.

5.1.4 Embedding students' prior experiences and understanding

> *"Meaningful [...] learning [...] requires both a meaningful learning set and the presentation of potential meaningful material to the learner. [...] and that the particular learner's cognitive structure contains relevant anchoring ideas to which the new material can be related."* (Ausubel, 2000, p.1)



In cognitive learning theory, the development of conceptual understanding is described as linking new information and ideas to existing knowledge structures while simultaneously adjusting old structures to fit new ideas. Ausubel (2000) describes this process of learning by stating that:

> *"In meaningful learning the very process of acquiring information results in a modification of both the newly acquired information and of the specifically relevant aspect of cognitive structure to which the new information is linked"* (p.3*)*

This process of connecting new ideas and concepts presented in the educational material to a learner's existing knowledge, adjusting existing knowledge, and constructing an improved understanding, can be designated as the principle of linking.

Dewey's concept of *connectedness in growth* can be seen in relation to Ausubel's concepts of *anchorage* and *linking*. Dewey (1997) instructs intervention designers, stating that

> *"the educator [...] must constantly regard what is already won not as a fixed possession but as an agency and instrumentality for opening new fields which*

> *make new demands upon existing powers of observation and of intelligent use of memory. Connectedness in growth must be his constant watchword."* (p. 75)

A view which we consider complementary to Ausubel's focus on the significance of existing cognitive structures is presented by Tiberghien. She emphasises the following regarding learners' understandings of learning activities:

> *The learners' existing theoretical framework is fundamental to his/her understanding of the whole situation. The situation includes all physical, mental, affective aspects"* (Tiberghien, 2000, p. 31)

We consider interactive science exhibitions to represent educational material that can generate educational experiences, provided that the designed material supports students in relating the experience during the visit to experiences prior to the visit.

As we have no empirical data related to anchorage and linking in the studies we conducted, and because this topic was not included in Hauan & Kolstø, 2014, we include the following discussion, based on other empirical studies that are informative with regards to linking, anchorage, and misconceptions.

In a qualitative study, Anderson, Lucas, Ginns, and Dierking (2000) investigated an extensive teaching intervention, including pre- and post-visit activities, and a visit to a Brisbane science centre. They compiled data from interviews with 11–12-year-old students and student-generated concept maps into Concept Profile Inventories (CPI). The CPIs describe cognitive development and knowledge transformation through different phases of educational programmes. Analysis of these CPIs revealed that knowledge was developed through all three phases: pre-visit, during the visit, and during post-visit activities. This thorough study also revealed instances of students constructing misconceptions during the programme or confirming prior misconceptions.

To prepare for a visit to the Technical Museum in Oslo, high school students wrote a text about their knowledge and attitudes concerning the focal subject prior to the visit.

After the visit, students reflected, in writing, on their previous statements based on the experience of the visit. By analysing these texts, Henriksen and Jorde (2001) found that the visit provided science learning outcomes for the majority of students. However, they also discovered, in some cases, that previous misconceptions remained and that new, alternative concepts had been developed as a result of the visit.

The design of a qualitative study by DeWitt and Osborne (2010) with 9–-11-year-old students visiting a science centre in Cardiff constructed the visit as a teaching intervention which included pre- and post-visit activities. The analysis of post-visit interviews revealed that information given prior to the visit (that visitors would be objects of research and that their experience would be recorded for use in the post-interviews) made students ready and prepared to learn. During the visit, researchers saw evidence of students applying their scientific understanding in their interpretations of the observations they made. However, post-visit interviews (or activities) revealed that students' understandings of phenomena, as demonstrated by exhibits, were often scientifically incorrect or inappropriate and students were often confused. When this was discovered, it was communicated to the teacher and the teacher then discussed both the phenomena and the incorrect interpretations with students in a post-visit activity at school.

The studies presented above inform us that misconceptions can be the result of a visit or can be confirmed by students' experiences during a visit. This may simply be because students do not understand what they are presented, due to their own lack of focus or low quality of the educational material. However, in line with theories of cognitive development (Ausubel, 2000; Dewey, 1997; Tiberghien, 2000), misconceptions can also arise from a lack of *relevant anchoring ideas*, or because existing cognitive structures contain prior misconceptions which a new experience confirms or strengthens. Regardless of the reason, it is important to be aware of the potential of negative learning outcomes resulting from a visit to a science communicating venue, especially since such visits are potentially powerful personal experiences. A study by DeWitt and Osborne (2010) presents a method to address this challenge which involves assessing students' learning outcomes and addressing eventual misconceptions.

The principle of linking implies that teachers should prepare students for educational tasks during a visit by providing them with relevant knowledge which can be used as anchoring points to which new observations and ideas presented in the exhibition can be linked. Also, intervention designers, exhibition designers, and staff may seek to facilitate linking. We are not aware of any studies focusing specifically on this issue. However, several studies have revealed that guided tours often follow a predetermined script that is inflexible in terms of responding to students' interests or expressed prior knowledge (Cox-Petersen et al., 2003; Bamberger & Tal, 2007).

The concept of *advance organizers,* as defined by Ausubel, provides a theoretical foundation for further research in using preparation to facilitate linking. Ausubel (2000) notes,

> *"an advanced organizer is a pedagogic device that [...] bridges the gap between what the learner already knows and what he needs to know if he is to learn the new material most actively and expeditiously"* (p.11).

According to Ausubel (2000), the teacher should produce, or be provided with, an advance organizer to present to students prior to a visit. With reference to Ausubel and others, Gurlitt and Renkl (2010) advocated for the use of advance organizers to activate previous knowledge to help learners focus on relevant information and support the assimilation of the new information. Osman and Hannafin (1994) describe two levels of prior knowledge. One level can be designated *significant prior concept-knowledge.* This implies that the learner can activate an existing, meaningful cognitive structure which can be further developed or modified. A less sophisticated level is designated *concept-relevant knowledge* (Osman & Hannafin, 1994, p.5) and involves a learner who does not have specific knowledge within the focal subject-matter but has some previous experiences that can be related to the topic. A quantitative study by Osman and Hannafin (1994) found that advance organizers which involved asking "*orienting questions*" (p.5) which aimed at activating everyday related *concept-relevant knowledge* enhanced 10th grade students' learning outcomes during a science lesson. This suggests that asking questions such as "*Do you remember that waterfall we saw at the trip to Bergen?"* can support students' understandings during a lesson about hydropower.

Advance organisers hold the promise of supporting the process of linking concepts presented, for example, by an exhibition, to general scientific ideas being taught at school. The effect of an advanced organizer is disputed, but its expediency is supported by Kisiel (2006) and Falk and Dierking (2000). However, development and use of advanced organizers has not been a strong focus within museum research.

For the intervention developed for Hauan et al. (2015), we addressed the issue of prior misconceptions by conducting a pilot study with semi-structured interviews which examined students' understanding of exhibits which would be included in the intervention. The information gained from these interviews was taken into account when the intervention was designed. As examining the development of students' cognitive structures was not part of our study, we can only hypothesize, based on cognitive development theory, that the way tasks were designed supported students in developing recognized understandings of focal scientific concepts. With the aim of connecting visit experiences to prior experiences, we used illustrations of focal phenomena and objects in real world settings (Hauan et al., 2015). These illustrations were further developed for digital presentation included in the digital pad and CFC (Hauan & Hällman, sub. 2016). The evaluation method applied in the studies revealed no data informing us of the efficiency of methods we used to address the issue of prior misconceptions and linking. We can therefore only hope that illustrations linked to the real world activated students' prior concept-relevant knowledge.

Summary

Learning can be described as a process of construction, where new information is linked to existing cognitive structures. This implies that a learner must have relevant/related cognitive structures which can provide anchorage for new information. This also involves providing learning material that supports students in linking prior experiences and the experience of exploring exhibits. One way to support such linking is to ask organizing questions, as suggested by Osman and Hannafin (1994). Another way, which we applied in our studies, is to use illustrations which show how the subject-matter is presented in a real world setting. As discussed in Hauan et al. (2015), we recommend combining these methods by designing advance organisers which hold real-world illustrations and related organizing questions. It was helpful for us to design for students living locally to us, because we had insight into likely prior experiences (e.g. if they live in the countryside, they have probably seen a tractor) and into what they know or should know. This insight can be achieved by:

- Gaining knowledge about students in an area, including learning about their neighbouring regions, and possible leisure time experiences.
- Studying local school curricula, text books, and talking to teachers, which can reveal prior knowledge related to a given subject.
- Talking to students in a focal age group to learn about prior *concept-relevant knowledge* or likely misconceptions or misunderstandings.
- Using the insight gained to design material which activates *concept-relevant knowledge,* e.g., real-world related illustrations, organizing questions, or a combination of these methods.

It is important to remember that most visitors are less interested in science than the staff of science centres. We need to strive to take the perspectives of students into account to generate an ELE where prior knowledge or experiences can serve as educational resources.

5.1.5 Creating active mental engagement in an embedded learning environment

In the four preceding sections of this chapter, we have discussed the challenges and potentials of embedding four elements: exhibits, text, peers and teachers, and prior experiences. We have limited opportunities to influence these four elements. However, we have significant influence on material designed for self-guided exploratory learning experiences. In this section, we discuss how this aspect, which can be called the fifth element, can be designed to create personal and thoughtful engagement.

Engagement

Learning, in terms of conceptual understanding, demands the mental process often called thinking. Thinking for learning requires personal engagement (Dewey, 2010, Novak, 2002). Hauan and Kolstø (2014) discuss how the issue of engagement makes the design of curriculum-based student activities different from designing for free-choice, informal learning. Instead of facilitating visitors in following personal interests, we need to find other ways to engage visiting students. Dewey (1997) reminds us of the need to balance the necessity of structure and individuals' need for personal influence or agency. Csikszentmihalyi and Hermanson (1995) argue that learning is a process that humans, by nature, find rewarding. In their article, they present what we consider guidelines to be incorporated when designing learning experiences in interactive science exhibitions:

> "*Research indicates that the natural motivation to learn can be rekindled by supporting environments, meaningful activities, by being freed of anxiety, fear,*

> *and other negative mental states, and when the challenges of the task meet person's skills*" (p. 35).

These guidelines remind us to ensure the following statement by Frank Oppenheimer will always be true: "*No one flunks museums*" (referred in Gardner, 2006, p.136). The guidelines also remind us that tasks must provide some level of challenge.

The majority of theory on learning presents learning as a process that is similar for all individuals. However, some researchers, such as Gardner (2006), argue that the nature of learning varies between individuals. We believe that the basic process, such as observing, reflecting, and assimilating is common for all, however, we also agree that individuals seem to have different interests and preferences related to learning. Based on work on the theory of Multiple Intelligences and through projects involving the study of learning activities, Gardner (2006) has developed what he calls "*Multiple Entry Points to Understanding*" (p. 138). We argue that these entry points should be considered as guidelines to create personal engagement in given tasks:

- A "*narrational entry point*" (p. 139) involves stories or other forms of narratives.
- A "*logical entry point*" (p. 140) involves structured arguments or discussions.
- A "*quantitative entry point*" (p. 140) involves numerical quantities and relations.
- By raising "big questions", one applies a "*foundational entry point*" (p. 140).
- By focusing on beauty or visual design, one applies an "*aesthetic entry point*" (p. 140).
- The "*experiential entry point*" (p. 141) is the core of interactive exhibitions.
- By encouraging cooperation, we apply a "*collaborative entry point*" (p. 141).

By including an extensive selection of entry points in the design of learning experiences, more students can be reached.

Some empirical studies are informative regarding methods for creating engagement in designed interventions (Hauan & Kolstø, 2014). A driving force in Cultural Historical Activity Theory (CHAT), is the joint productive activity involved in producing an end product (Engestrom, 1999; Roth, 2009). One study, which involves CHAT comes from DeWitt and Osborne (2007). Students were instructed to take pictures of a set group of exhibits they found interesting, write texts about the exhibits, and create a poster exhibition when they returned to school. This task was designed to generate engagement with the goal of creating a poster exhibition, based on the cooperative exploration of exhibits of students' choosing, as an end product. The study indicates that students were personally engaged and their interactions resulted in fruitful, subject-related discussions and writing. Two other studies of note applied narratives as a way to create engagement. First, Henriksen and Jorde (2001) describe a project that used a "real life" story as a narrative, and second, Metz (2005) writes about how role play can create engagement. Other studies indicate that the use of technology can also help in creating engagement (His, 2003; Hwang et al., 2012; Yatani et al., 2004).

A study conducted at a science centre by Kahr-Højland (2010) of an intervention which did not focus on science learning (therefore, not identified by Hauan and Kolstø, 2014) is of particular interest. Students were assigned a role in a digital, game-based narrative where they interacted via mobile phones. In the initial phase, students worked alone to build a personal profile based on exhibit exploration. Then, they worked in groups of peers. Finally, the plot was revealed and the game completed. An evaluation of the intervention indicates that students were personally engaged.

The intervention presented by Hauan et al. (2015) applied two methods to engage students: facilitating group-work through direct instructions to work together and "*Concept Cartoons*" (Keogh & Naylor, 1999) which involve dialogue between characters that students can identify with. A comparison of the paper version of *GEL* handouts with handouts classified as *Open exploration* and *Traditional worksheet* (Hauan & Hällman, sub. 2016) indicate that facilitating group-work did help students to engage in tasks and work together as a group. For the same study, we designed a "digital version of GEL which, in addition to the paper version included open instructions to take pictures based on students' judgement and formal assessment through feedback on selected options. This can be characterised as modest gamification. The analyses indicate that gaming-influenced feedback does enhance engagement, however, the novel and complex digital presentation seemed to interfere with the inclusion of peers in joint work (Hauan & Hällman, sub. 2016).

Thinking

As discussed, learning demands thinking. And, as stated by Millar (2004),

> *[…]" if the task requires the students to make links between the domain of objects and observables and the domain of ideas, the structure of the task must 'scaffold' their thinking".* (p. 12)

The question is then, how should one scaffold for thinking to lead to learning? Some guidance is provided by Dewey (1910) who states that "*thinking in short, must end as well as begin in the domain of concrete observations, if it is to be complete thinking*" (p.96).

Dewey (1910) elaborates on his view and lists five phases of explorative thinking:

I. "*a felt difficulty*
II. its location and definition
III. suggestion of possible solution
IV. development by reasoning of the bearings of the suggestion
V. *further observation and experiment leading to its acceptance or rejection*" (p. 72)

An analogous list of phases in a reflective exploratory process, developed as a result of Project-Zero and presented by Ritchhart, Church, and Morrison (2011), can be considered a framework for designing for thinking. This framework is more complex, describes more phases than Dewey's, and is less specific about the need to complete thinking processes through observation.

In his book, Mercer (2000) argues that communication between individuals while engaged in a common task can result in a co-ordinated intellectual activity which enhances the quality of the educational experience of solving tasks. With reference to the researcher Barbara, he recommends that activities should guide learners to participate in collaboration and shared understanding. He uses the term "*Interthinking"* (Mercer, 2000, p. 16) to describe the process of *thinking together,* resulting from being engaged in a joint, coordinated activity.

Four of the exhibit-related tasks in the intervention presented by Hauan et al. (2015) and the Digital GEL presented in Hauan and Hällman (sub. 2016) included questions and requested answers, while a fifth task involved an assignment to be recorded. Students were encouraged to cooperate and discuss proposed answers and, in this way, think together. Discussion and agreement were also the aim of the recorded task. Analysis presented in Hauan and Hällman (sub. 2016) indicates that the GEL design resulted in cooperation while solving tasks and generated what we designated as Multi Modal Discussions (MMD), which involve social interactions that are considered as indicators of *interthinking,* reading, or listening to text, and joint physical exploration of exhibits presenting focal phenomena.

Summary

Engagement within an ELE must result in thinking if it is to support students' progress towards conceptual understanding. Productive thinking demands personal engagement and design of material for self-guided, exploratory learning experiences must aim to result in such engagement. This material, which can be called the fifth and embedding element, needs to both integrate the four previous elements and facilitate personal and engaging thinking.

- The tasks must guide students' observation and thinking towards the focal concepts.
- The tasks must facilitate *interthinking,* as discussed by Mercer.
- To be engaging, the learning environment needs to have a structure that balances the need for focusing students and with the importance of letting students have some influence over how the visit proceeds.
- Material provided should facilitate what is described by Csikszentmihalyi as a flow experience.
- Encouraging students to gather information that can be presented by, for example, posters can create engagement in the process of working towards an end product, as described by Activity Theory.
- We should also take into account that people are engaged by different things. Some of Gardner's entry points are already included in the design we have described (*collaborative, experiential*). With an appealing design and an engaging story that supports structured arguments and discussions, other entry points can be included (*aesthetic, logical, narrational*). If big questions (e.g. related to science and society) or numerical quantities and relations fit the related subject-matter, they can also be included as well (*foundational and quantitative entry points).*

It is demanding to cover all dimensions listed above, nevertheless, they should be considered as goals in designing material for self-guided exploratory learning experiences. The material can be presented with simple hardware, such as paper and magnet boards (e.g. Hauan, DeWitt and Kolstø, 2015), through assignments and photo cameras (DeWitt & Osborne, 2007), or with sophisticated IT equipment (Hauan & Kolstø, 2014).

Narratives or entry points are also supported by research (Hauan & Kolstø, 2014), including Bruner’s (1990) who sees narratives as humans’ intuitive approach to making sense of the world and themselves. A tool or method that has the potential to include both narratives and flow, as well as the other dimensions listed above is gamification, especially when presented with digital multimedia equipment.

Bizzocchi and Paras (2005) state that games have the potential to generate learning environments that create active learning experiences and facilitate intrinsic motivation. An intervention presented by Kahr-Højland (2010) is an example of the potential of narratives incorporated and communicated by digital gamification. Exploration of innovative ways of using digital gaming and narratives would be an important area for further research in the design of self-guided learning experiences. Much can be achieved through knowledge sharing and cooperation between people within the fields of education and gaming.

5.1.6 Relating the design framework for Embedded Learning Environment to other frameworks

A model for describing learning at museums, including venues such as informal science institutions, is the CML, presented by Falk and Dierking (2000) and further developed by Falk and Storksdieck (2005). This model examines elements and contexts that influence the outcome of a visit characterized by free choice. The CML has influenced the development of ELE, but the latter takes another perspective and is valid for visitors with a different agenda. The ELE design framework concerns the design of guided learning experiences with an intended educational outcome. This is possible for school visits because insight can be gained into visitors, their previous experiences, and schools’ and teachers’ requirements. The combination of these insights and knowledge about our venue guides us in the work of setting up an ELE, and in creating active and motivating learning experiences, as described in the previous sections.

To design an ELE which results in a high-quality educational experience, students' previous experiences need to be incorporated and insight about how the visit can support students' upcoming learning process is necessary. However, the ELE design framework focuses on students' experience during a visit to an interactive science exhibition. A design framework that takes on a more holistic approach is the Framework for Museum Practice (FMP), developed by DeWitt and Osborne (2007).

The FMP is applicable to all types of museums and includes a focus also on pre- and post-visit activities. The ELE design framework is hopefully compatible with the FMP, by homing in more precisely on what happens during the visit itself. The process of designing a school's visit to an interactive science exhibition should be informed by both an ELE and the FMP.

6. Discussion

This chapter discusses key findings, claims, concepts, and hypotheses resulting from this PhD project.

The following abbreviations are used to improve readability:
Paper-I for Hauan & Kolstø, 2014;
Paper-II for Hauan, DeWitt & Kolstø, 2015;
Paper-III for Hauan & Hällman, submitted 2016;
ELE-chapter for the Chapter five: Proposing a Framework for Designing Embedded Learning Environments.

6.1 Guided Exploratory Learning: structure and openness

Views on how science centres should be used can be classified into two perspectives. One perspective argues strongly that exploration should be governed by visitors' free-choice. Another perspective argues for structured exploration if the aim is to achieve a defined, curriculum-based learning outcome. In the following sections, we present literature and studies related to both perspectives. We then argue for our design concept for school visits, which we designate Guided Exploratory Learning (GEL). We focus the argument for GEL design on the need to engage and support students in what we consider fruitful learning activities.

Free-choice exploration is strongly argued for by Falk and Dierking (2000), among others, as the basic principle for learning in venues such as science centres. They present visitors' freedom of choice to control exploration as a key element of a contextual model of learning and state that this is a significant requirement for personal engagement and learning (Falk & Dierking, 2000). A similar view is presented by Hein (2002) who believes free-choice visits, where a visitor decides what to engage with, best exploit the way venues such as science centres are designed, as opposed to visits where content and learning agendas are defined by someone other than the visitor.

Several studies have investigated schools’ use of venues such as science centres. In one such study, Bamberger and Tal (2007) use the term *controlled choice* to describe designs that provide students with some control over how a visit is conducted while also guiding students towards predefined educational activities. A study by DeWitt and Osborne (2007) presents the Framework for Museum Practice (FMP). This is a framework that involves controlled choice and invites teachers to engage students in the selection of topics and exhibits to explore within a defined subject area.

Paper-I resulted in a design concept for visits to support students’ process of understanding specific concepts. This design concept was designated GEL. Evidence from research on structure led us to conclude that the nature of a GEL visit should be designed in a way that provides both personal freedom and structure. As this design aims to guide students along specific educational activities, GEL design involves tight scaffolding (Wood, Bruner, & Ross, 1976) which differs from structures discussed in previous studies (Bamberger & Tal, 2007; DeWitt & Osborne, 2007). Studies presented in Papers II & III support the need for tight scaffolding. The conceptual framework for the GEL design presented in Paper II and further elaborated on in the theoretical framework chapter of this thesis contains four principal elements related to the activities: observation, reading, cooperation, and connections to prior experiences. To determine whether exhibits facilitated these activities, we conducted a pilot study. In the pilot study, staff members observed students’ exploration of exhibits. These observations were informed by two aspects. First, staff members were made aware of the results from a study by Anderson, Lucas, Ginns, and Dierking (2000) which discusses how students' previous misconceptions can result in new misconceptions or confirm prior misconceptions. This led staff members to focus on identifying students' prior misconceptions and misunderstandings. Their findings were, in some cases, surprising. Second, the intended focus of observations was at times outside of students' field of vision. Observations were sometimes hindered for trivial physical reasons or interaction responses that narrowed students’ focused field of vision. Examples of findings from the pilot study are reported in the notes of Paper II. These lessons were incorporated into task designs, by using questions that attempted to guide students’ observations and thinking. The level of guidance was customized to the characteristics of the exhibits. Findings from analysis presented in Paper-III suggest that the tight scaffolding of GEL designs helped students to be involved in activities related to the principal elements of the conceptual framework. This contrasts with the experience of students who were provided with material based on the *open exploration* and *traditional worksheet* designs, which resulted in little reading of the provided text, and little cooperation or sharing of ideas and impressions within groups. We also found that observation of focal objects and phenomena were helped by a GEL-design.

Personal engagement is considered to strongly enhance the outcome of a learning activity (e.g. Dewey, 1910; Ausubel et al., 1978). Venues such as science centres are considered by several researchers to be arenas designed for free-choice learning (e.g. Falk and Dierking, 2000 & Hein, 2002). This view implies that free-choice is a requirement for personal engagement and learning in such venues, however, this is only one of many ways to create personal engagement. Examining this argument entails looking for ways to engage students. As GEL design involves students' exploration that is not characterized by free-choice, such design involves taking on the challenge of finding other modes of engagement.

Guidance for addressing the challenge of designing for an engaging learning environment is provided by several researchers. Dewey (1997) notes similarities between engagement in learning activities and games, noting that both games and learning require rules. Csikszentmihalyi and Hermanson (1995) recommend the design of a structure that is open so learners can influence how a visit is conducted, but also provides clear goals and appropriate rules. The concept of *flow*, developed by Csikszentmihalyi, provides guidance for facilitating intrinsic motivation and thus personal engagement. Requirements for flow, as listed by Csikszentmihalyi and Hermanson (1995), include "*supportive environments, meaningful activities, [absence of] negative mental states, and [harmonization] with person's skills*" (p. 35). Elements of flow are also similar to several elements of scaffolding (e.g. a supportive environment that is well matched to the degree of skill of the learner) as presented by Wood et al, (1976). Both Dewey (1997) and Wells (1999) advise that a learning environment must be an inviting environment that allows all students to participate by expressing their thoughts and ideas. Furthermore, students should be given the opportunity to contribute based on their own skills. Gardner (2006) argues that activities within the learning environment should allow for what he designates as "*multiple entry points to understanding*" (p.138). As presented in Paper-II, we aim to embed bodily/kinaesthetic, verbal (reading and writing), and social experiences to create a learning environment which offers multiple entry points to conceptual understanding. Supported by what we learned from Paper-II and Paper-III, we argue that GEL design interventions generate a learning environment where nearly all students are engaged or deeply engaged in contributing to solving the given tasks. This suggests that GEL design can result in an engaging and supportive learning environment.

Both Bamberger and Tal (2007), and DeWitt and Osborne (2007), argue that students should be allowed some degree of control in tasks on a school trip. Material designed for GEL (Papers II and III) was given to groups of students who were also provided with a map of the exhibition, which included the location of specific exhibits. Students were then asked to organize the execution of the tasks. This resulted in one or two students taking on the responsibility of group-organizers (Paper-III). These self-appointed organizers strove to include all group members and structured the execution of task-solving. This finding suggests that GEL design has the potential to engage students by giving them control of the execution of tasks.

Fruitful thinking is described by Dewey (1910) as an exploratory process that starts and ends with the observation of phenomenon. Honey and Mumford (1992) remind us that people are different and may enter a thinking process in different ways. For example, some might begin with careful reflection, while others most likely start by experimenting in an open-minded way. They all need, however, to complete the exploratory thinking process to gain a meaningful learning experience. The short transcript presented in table 4 in Paper-II shows that the students Tina and Bob address problems differently. While Tina focused on propositions presented in the task text, Bob focuses on what he could observe. This example from Paper-II illustrates that a learning environment can allow for different ways to contribute to a joint exploratory process when solving a given task.

Moderate gamification (Deterding, Dixon, Khaled & Nacke, 2011) was applied in the digital version of GEL-design for the study presented in Paper-III with the aim of providing feedback in an engaging manner. It was found that this gamification resulted in the expression of positive emotions; however, there was no indication of enhanced overall engagement in task-related work. Nevertheless, inspired by the success of the gaming industry (Deterding et al., 2011), and based on a study by Kahr-Højland (2011) that suggests that gamification can strengthen students' engagement, I argue that modest gamification has the potential to facilitate personal engagement.

The examples presented above illustrate that there are a range of ways to facilitate personal engagement, such as an inviting learning environment, self-organization, flexibility in participation, and the application of modest gamification. It could be argued that designs for GEL provide more possibilities for the creation of personal engagement than free-choice. The exploitation of these possibilities suggests a range of possible research projects.

GEL-design can provide for personal freedom in terms of allowing individual differences to influence how given tasks are worked with by providing openness within a defined structure. Providing openness by allowing: self-organization of group-work, different ways to contribute to joint explorations, participation by presenting one's own thoughts and ideas, using one's own skills, and by including multiple entry points to conceptual understanding.

Our findings suggest that a structure which involves tight scaffolding, such as that applied in the GEL-designs presented in this study, supports fruitful engagement in learning activities. These activities incorporate the four principal elements (exploration of phenomena, reading involving focal scientific concepts, group work, anchorage) of the conceptual framework developed to design GEL (Paper-II; Paper-III). Based on previous research and our own findings, we also argue that GEL-design has the potential to facilitate a high degree of personal engagement in curricula-based learning activities.

6.2 Evaluating educational quality, focusing on resulting behaviours

In Paper-I, we argued for applying a process based approach to evaluation rather than focusing on the outcomes (e.g. conceptual gains as measured by a post-test). This approach resulted in an evaluative framework proposed in Paper-II and further developed and applied in Paper-III. In the following paragraphs, we briefly elaborate on the argument for using this framework for evaluation by using practical work as a lens to reflect on similarities with the challenge of evaluating practical work in a school setting.

As presented in the theory section of this thesis, group exploration of interactive exhibits and associated scientific texts has features that correspond to what Millar (2004) designates as *practical work,* as well as what Tiberghien (2000) describes as modelling activity. Millar (2010) points to a lack of expedient methods for evaluating the quality of practical work with regard to its effectiveness for enhancing students' conceptual understanding. Similarly, in reviews, Hofstein and Lunetta (1982; 2004) suggest that there is a lack of empirical data that supports the assumption that practical work in laboratories benefits students' learning. Regardless of the lack of strong empirical support, Hofstein and Lunetta (1982; 2004), Millar (2004), and Tiberghien (2000) argue that practical work helps students build a conceptual understanding. In line with this approach, and based on literature presented in the theory section, we also argue that practical work involving GEL experiences supports students' learning. Rennie, Feher, Dierking, and Falk (2003) state that learning is a cumulative process and that it is challenging to evaluate the resulting educational outcome of one specific experience of practical work. In another study, Anderson, Lucas, and Ginns (2003) took on this challenge and evaluated the outcome of practical work in a science centre by applying theory presented by Ausubel et al.

(1978) to investigate changes in students' conceptual structures. The study involved investigating changes in concept maps constructed by the students prior to the visit, after the visit and after post-visit activity. This study by Anderson et al. (2003) showed that the evaluation of the educational quality of practical work in science centres with a focus on learning outcomes can be accomplished. Moreover, the study also confirmed that it is resource intensive. The approach we have proposed for evaluating educational quality with a process approach involves a framework of three principal elements. The principal elements are 1) summarising overall group behaviour, 2) a behaviour code structure for overall engagement in the prepared learning environment, 3) a behaviour code structure for multi-modal discussions (MMD).

A group of students is a group of peers where no member has formal authority and members within the group have comparatively equal levels of conceptual understanding, however, variation in prior experiences and ideas related to focal concepts is likely. This provides the potential for open-minded, joint exploration which involves sharing and responding to ideas and understandings. Such joint work has the potential to be a resource for development towards conceptual understanding (e.g. Mercer, 2000; Wertsch, 1991) when it is informed by a knowledge resource, and feedback is provided (Wood et al., 1976). Paper-III has shown that the organization of group-work and the resulting quality of the joint work is highly influenced by the material given for self-guided learning. Our studies have also shown that scaffolding within groups can encourage students to take on the role of organizers. How the material provided influences the occurrence of self-appointed organizers, how they operate, and how other group members respond is considered to significantly influence the educational quality of an experience. A description of overall group behaviour as presented in Paper-III is therefore a principal element in the evaluation framework.

The aim of practical work, as described by Millar (2004), is to support understanding of scientific concepts by supporting students' connections between observable objects and phenomena and the words that label these observables. The exhibits provide the opportunity for interactive observation. The words are included in texts that are presented by the material provided or exhibit labels. A requirement for practical work is therefore that these educational resources are used. How the material designed for self-guidance influences students' observations and perception of text is therefore significant in terms of evaluating the educational quality of the provided material. The evaluative framework therefore includes a behaviour code structure for overall engagement in the prepared learning environment, as presented in table 3 of Paper-III.

The evaluation of deeper levels of engagement addresses participants' thinking, which is considered by several researchers and thinkers within learning (e.g. Dewey, 1910; Novak, 2002) as a requirement for ongoing development of conceptual understanding. Verbal discussions between learners are a process that requires thinking by participants and are considered by several researchers (e.g. Wells, 1999) to support learning. What we have designated as MMD also involves considering non-verbal expressions as contributions to a discussion which we, in agreement with Mercer (2000) and Wertsch (1991), believe to support learning (discussed in Paper-II). Evaluating an educational process by identifying behaviours within the MMD category (listed in table 4 of Paper-III) involves analysis based on students' interaction with each other and with provided educational material. This implies the evaluation of the ability of the provided material to generate MMD and thereby the ability to mediate the content which the material is designed to convey, thus potentially resulting in conceptual learning. The claim that behaviours within the category of MMD are indicators that learning is occurring is a hypothesis developed on the basis of learning theory. Activities that are designed to result in MMD-related behaviours are designed in accordance with theory related to the development of conceptual understanding (further elaborated on in the chapter four, Theoretical Framework). We argue that because MMD behaviours correspond to activities that are considered to support learning, this relationship strengthens the hypothesis that the evaluation of MMD is an evaluation of an ongoing learning process.

To evaluate practical work in school settings, Abrahams and Millar (2008) developed an evaluative framework for educational materials based on a model presented by Millar (2004) which defines two *effectiveness levels*. Effectiveness level 2 involves evaluating students' achievement of learning goals. This level can be considered as related to outcome evaluation. Effectiveness level 1 involves evaluating educational material by investigating whether the material results in fruitful learning activities. This level can be considered as an evaluation of the learning activities in which students are engaged, thus, whether the material supports a process towards conceptual understanding. We therefore argue that the evaluative framework developed in this study (Papers-I,II,III) can be considered as corresponding to what Millar (2004) defines as Effectiveness level 1.

Practical work related to science learning has the same aim in school settings and interactive science exhibitions. As discussed, practical work also faces the same challenges in these settings regarding the evaluation of its effect on learning. In their study, Abrahams and Millar (2008) focus on evaluating learning experiences from a process perspective, as we have done in our study. Our proposed evaluation method corresponds to a process evaluation approach, presented by Rennie et al. (2003), which involves focusing on students' behaviour. We assert, supported by similarities with school settings and because we have based the proposed framework on theory on learning and grounded it in empirical findings, that the framework is an expedient and a noteworthy contribution to a discussion about the design and evaluation of material for self-guided exploratory learning experiences in interactive science exhibitions. We also hope that it can inform a discussion concerning the quality of practical work in schools.

6.2.1 Towards an expedient quality evaluation tool

To investigate and enhance the educational quality of visits, the experience needs to be evaluated. A feasible evaluation tool could make evaluation a part of staffs' responsibilities in the design and redesign of educational programmes (Barriault & Pearson, 2010). Based on our experience, and that of others working in this area, we argue that the evaluative framework developed can be a foundation for the design of a feasible tool to evaluate self-guided experiences in interactive science exhibitions.

In a study on leisure time visits, Allen (2002) investigated visitors' discussions to investigate the quality of this potential learning activity. Based on her experience, Allen (2002) argues that there is a need for an expedient standardized coding structure to analyse visitors' verbal behaviour. In Paper-I, we argue for a process-based perspective for the evaluation of the educational quality of activities that students are engaged in. The following sections present our practical experience in developing the evaluative framework structured by behavioural codes with a perspective of process. We also discuss how this coding structure can be developed into a feasible tool for evaluating self-guided exploratory learning programmes for schools.

The approach we used in Paper-II and Paper-III involve basing evaluation on identified behaviours which are considered indicators of fruitful learning activities. These behaviours were identified by transcribing and analysing video recordings. NVivo 10 software was chosen for transcribing and coding, as presented in Paper-II. With this software, the transcripts and video recordings can be synchronized. In this way, a user can scroll through the transcripts and recordings simultaneously. Transcribing demands a high level of focus and was only possible to conduct over relatively limited time periods (e.g. a few hours at a time). The total time necessary for transcription varied depending on the behaviour and number of group members. An approximate ratio of transcribing time to duration of the video is 50:1. The structure of the codes developed and coding rules for two classes of behaviours was included in a coding manual and integrated in a structure designated as Nodes in the NVivo 10 software. The resulting ratio of coding time to length of transcribed recordings was roughly 10:1. This results in a total ratio of coding to video duration of 60:1. For analysis presented in Paper-III, behaviours within the classes of overall engagement in the material learning environment and MMDs (Paper-II&III) were integrated into the European Exhibition Evaluation Tool (EEET) software (www.eeet.eu). This is software for the direct analysis of video recordings through pressing virtual screen buttons when behaviours occur. The occurrences, including timestamps, are registered in a Microsoft Excel file. The reconfigured EEET tool enabled us to code video recordings at almost the same speed as the real time speed of recordings; however, video analysis was conducted for individual students to ensure the required focus. This meant that the ratio of coding time to recording time was roughly 1,2 multiplied by number of students. For a group of five students, this resulted in a coding time to recording time ratio of approximately 6:1.

Allen (2002) suggests that coding can be completed directly from recordings. Our experience shows that coding directly from video recordings is about 10 times faster than when videos are first transcribed and then transcriptions coded. Based on our experience, we support Allen's (2002) suggestion that analysing directly from recordings can be an efficient method for analysis. We therefore suggest that the integration of the coding structure for *overall engagement* and MMD, presented in Paper-III, utilising software such as EEET would be expedient. Furthermore, an interface for writing short descriptions of *overall group behaviour* (Paper-III) would be necessary for such software to be a complete evaluation tool for self-guided exploratory learning experiences.

Allen (2002) argues for the development of a scheme of coding structures that can be used for evaluating the educational quality of visits to venues such as science centres. We hope that the evaluation framework proposed by this study can be considered a contribution to such a scheme. We believe that our proposed framework for evaluation of material for self-guided exploratory learning experiences, and the framework for evaluating single exhibits presented by Barriault and Pearson (2010) (presented in chapter 3.2.2) and should be considered as frameworks that can be integrated into an expedient and feasible software tool to enhance the educational quality of visits to interactive science exhibitions.

6.3 Embedded Learning Environments, a participant inclusive design approach

The design guidelines of the ELE framework involve an approach where both programme participants and resources from a venue are considered educational resources. We present the background and rationale for an ELE framework and discuss how it implies a shift from focusing on what the exhibition has to offer to focus on how the exhibition and students' resources together can be embedded into a holistic learning environment. We also briefly discuss how ELE, in its approach and purpose, differs from the Contextual Model of Learning (CML) developed by Falk and Dierking (2000).

The framework designated as ELE was developed to provide guidelines for using exhibits, text, groups of students and teachers, and students' previous experiences as educational resources and to facilitate students' personal engagement. The development of ELE is grounded in literature on learning presented in chapter four, findings from empirical studies represented in Paper-I, and the empirical studies we conducted presented in Papers II and III. The framework is presented in chapter five of this thesis.

In the following paragraphs, we briefly discuss how the idea of the ELE framework developed throughout the project. Paper-I shows that complex exhibits can result in misconceptions or confirm/strengthen prior misconceptions. This led us to include a number of exhibits in an educational path, where each exhibit-related task focused on a limited number of focal objects and phenomena, guiding students' exploration. Knowledge gained from the review also helped us to be aware of prior misconceptions when we observed students in the pilot study, presented in Paper-II. The studies presented in Papers II and III failed to identify whether illustrations (presenting phenomena in everyday contexts) supported anchorage in students' existing cognitive structures. Methods to facilitate and identify anchorage would be of significant interest for further research. The concept of *advance organizers,* developed by Ausubel (2000), and the principle of activating prior knowledge, as described by Osman and Hannafin (1994), seems promising in terms of guiding such research. The pilot study also informed us of the need to guide students' observations and how to design the material provided to them, in terms of how to encourage students to engage with the material and which concepts to include. In the research presented in Paper-III, we learned that the design of tasks has a significant influence on how group work is organized, in particular, the emergence of self-appointed group organizers and how they operate. Further development of guidelines for facilitating fruitful group interactions and teacher involvement would be of significant interest for further research. In agreement with Wells (1999), we consider work by Lave and Wenger (1991) concerning how people with different resources and knowledges can grow through working together promising in terms of guiding such research.

In Paper-I, we discuss how our view on schools' use of venues, such as a science centres, differs from views on leisure-time visitors' use of these venues, as described in the framework designated as the CML (Falk & Dierking, 2000). The CML is a descriptive model that analyses how three contexts, *personal, sociocultural,* and *physical,* shape the nature and outcome of a visit. As the CML describes free-choice learning situations, it is not developed to guide the design of specific educational outcomes. The principal difference between CML and ELE is that ELE aims to be a framework for designing for human and material elements to be embedded in a learning environment where the elements are considered educational resources, whereas CML is a model for describing how these resources shape *free-choice learning*. To use the resources of ELE, knowledge about resources and how they come together is necessary.

Facilitation of concept learning by designing for GEL experiences in an ELE*,* and evaluation of engagement and MMD, implies a shift in the role of staff as guides. This involves the design and evaluation of material for self-guided experiences, gaining new knowledge about visitors, and new insights into the mediating function and potential of material presented to the visitors.

6.4 Integrating visit experience into pre- and post-visit classroom activities

The potential for a visit to be an educational resource for school-based, curriculum learning can be strongly enhanced by integrating a visit into classroom work (Dewitt & Storksdieck, 2008). A question is therefore how resources for productive integration should be designed? In this discussion we will briefly present guidance from previous studies related to the facilitation and design of pre- and post-visit activities. We will also present how this guidance has been built upon and informed pre- and post- visit resources designed for integration of the visitors' experiences resulting from this thesis research. (Material referred to in this discussion is presented at: www.vilvite.no/skole-barnehage/laeringstilbud/show/bak-stikkontakten/)

Integration requires preparation, including information concerning practicalities related to the visit to avoid negative effects caused by novelty related stress, as discussed by Kubota and Olstad (1991). Studies also suggest that both cognitive and affective outcomes are enhanced if students are prepared for the content of an educational experience (e.g. Anderson & Lucas, 1997; Jarvis & Pell 2005). Tiberghien (2000) notes that the results of practical work which aims to support connections between observations and theory are influenced by students' prior knowledge, arguing that students should be prepared for upcoming learning situations and its learning goal. In Osman and Hannafin (1994), which addresses the issue of preparing students, the researchers, based on Ausubel's (2000) concept of an *advance organizer,* present what they designate *orienting questions* as a tool for preparing and activating concept-relevant prior knowledge.

For all school programmes offered by VilVite, the need for general preparatory information is addressed by material concerning the subject-matter and the content of the school programme and its organization. Inspired by the work by Osman and Hannafin (1994), we designed a web-based drag and drop preparation task. Illustrations accompanying the tasks relate to students' prior concept-relevant knowledge by relating to students' everyday lives. The task asks students to drag labels which change from names of relevant objects to pictures of exhibits included in the programme if the labels are dragged and dropped at the correct location. In Paper-III, we present the hypothesis that students who become self-appointed group organizers will be helped in their efforts to include other students if they have been presented material with a GEL design through multi-media pads prior to the visit. Based on this hypothesis, we decided to present the multi-media pad material developed for Paper-III and make an instructional video available on the internet. Most visiting classes during the first four months of programme operation reported that they watched the video and initial analysis indicates that the instructional video increased group member engagement in joint task solving (data from this period is not documented in this thesis).

Several studies have examined situations where pre-visit activities are combined with post-visit activities (e.g. Anderson et al., 2000, 2003; Rennie, 1994). These studies indicate that post-visit activities, especially when combined with pre-visit activities, support recapturing the experience and stimulating reflection on observations made during the visit, enhancing the process of knowledge development. Dewitt and Storksdieck (2008) advise that students should collect their experiences and base post-visit activities on these collected experiences. Tiberghien (2000) advises that students should follow-up on practical work by expressing their personal understandings in different modalities, for example by writing texts or orally. Watson (2010) found that interaction with interactive exhibits made students better prepared to learn from post-visit experiences when an expert explains phenomena that exhibit were designed to present.

To facilitate recapturing experiences and stimulate reflection, teachers of visiting classes are given access to a database of pictures taken by students with multi-media pads provided during the visit. For methods for post-visit reflection, as advised by Dewitt and Storksdieck (2008) and in line with Tiberghien (2000), teachers were recommended to ask students to give presentations in the classroom or at home. To follow up on Watson’s (2010) finding related to preparation for experts’ explanation, videos about the exhibits that were included in the programme which present and explain the scientific concepts they are designed to present are made available as a resource for post-visit activities.

In Paper-III we reported that digital presentation of the material for self-guidance seemed to make it more challenging to include the other students in solving the tasks. Despite this, we decided to use a digital presentation for two reasons. Firstly, because of the hypothesis that the challenge of peer inclusion can be resolved through information about the operation of materials prior to the visit. Initial analysis of group operation and feedback from visiting classes on the use of this video suggests the video had the intended effect. Secondly, digital technology enables photos during task work to be available for post-visit activities via the internet. Digital technology was also applied to support the activation of prior knowledge and for post-visit presentations and explanations of focal concepts.

Based on presented studies and feedback from visiting classes, we argue that the presented resources have the potential to support integration of visit experiences in classroom settings and is thus an educational resource for school-based curriculum learning. However, Anderson and Zhang (2003) found that teachers do request material to prepare for the visit, but expressed little interest in resources produced for post-visit activities (Anderson & Zhang 2003). This finding suggests that there is a need for further research on how resources for integration should be designed and in particular how to facilitate for post-visit activities

6.5 Conclusion and implications

This section relates the work of the current study to work within this field that has inspired our thinking.

Visits to venues such as science centres are considered by several researchers to have the potential to be educational resources for science learning in schools (e.g. Kisiel, 2013 Rennie, 2014). Others consider that such venues are arenas for free-choice learning, where what and how to learn is decided by the visitor (e.g. Franse, 2012). Falk and Dierking (2000) note a conflict in using venues such as science centres for curricular learning, particularly "*given the very different cultures and realities of free-choice and compulsory learning*" (p.227). One can disagree with this stated conflict, nevertheless, it illustrates the challenge of using science centre exhibitions as educational material for curriculum-based concept learning. However, based on a growing number of research projects in this area, a review by DeWitt and Storksdieck (2008) calls for research to build on gained knowledge and develop ways to implement this research-based knowledge. Our study reflects this call by being based on research in this field and theories on learning. By basing our study on theories of learning recognized in school contexts, we strengthen the argument that this theory is applicable both in schools and in the context of science centres.

The Framework for Museum Practice (FMP) developed by DeWitt and Osborne (2007) provides principles that guide the design of visits and the integration of these experiences into the classroom. The design concept Guided Exploratory Learning (GEL) is applicable to visits to interactive science exhibitions which aim to support students' understandings of focal concepts. While FMP is an overall framework applicable for all museums and similar venues, GEL focuses on interactive science exhibitions. We consider GEL to be a compatible supplement to FMP. It supplements FMP by providing guidance for facilitating and scaffolding students' exploration of phenomena, reading involving focal scientific concepts, group work, and connections to previous experiences. For GEL, the focus is the visit, whilst FMP also focuses on guiding the integration of the experience into classrooms.

Developed by Falk and Dierking (2000), CML is a framework that provides a lens to analyse free-choice learning in venues such as science centres, describing the many personal, social, and venue related factors that influence the learning outcome of a visit. The Embedded Learning Environment (ELE) framework involves broadening the focus from the venue as a learning environment to also considering school curricula, students, and teachers as educational resources that comprise the learning environment. This is feasible because we can gain knowledge about these resources.

While CML describes free-choice learning, ELE guides knowledge gathering and design for facilitating and enhancing compulsory (or curriculum-based) learning.

As discussed, expedient methods for evaluating the quality of practical work are lacking. This is the case for both school and out-of-school contexts. We argue for applying process-based approaches for evaluation of visit experiences with a focus on students' verbal and non-verbal behaviours. We hope that the results of our studies, together with results from studies in a school context that focus on students' verbal and non-verbal behaviours such as gesture (e.g. Givry & Roth, 2006; Mestad & Kolstø, in press), can contribute to a discussion on the application of a perspective of process for the evaluation of the quality of practical work in both school and out-of-school contexts.

The design of GEL and ELE involves generating behaviours related to Multi-Modal Discussions (MMD), specific *engagement in the learning environment*, and unique *group dynamics,* including teacher involvement. By basing the evaluation of the educational quality of learning programmes on generated behaviours, the results can directly inform the optimization of existing programmes or the future designs of new programmes. This implies that we can learn more about intervention design from evaluations based on generated behaviours then evaluations based on outcome.

Development towards conceptual understanding within science includes an active, individual process of cognitive development (e.g. Piaget 1935; 1965) which is shaped by existing cognitive structures resulting from prior experiences (e.g. Ausubel, 2000). Practical work, which facilitates connections between observables and theory, as described by Millar (2004), and joint learning activities with peers, as advocated for by, for example, Wells (1999), are considered to support individuals' progress towards conceptual understanding. We argue that our study, by providing guidance for facilitating connections to prior experiences, joint activities, and guiding students' practical work (involving the exploration of exhibits and related text), can enhance the exploitation of the educational potential of interactive science exhibitions. We also argue that guidance for changing the focus from an exhibition to the needs of visiting students and teachers, as argued for by DeWitt and Osborne (2007) and Bransford et al. (2000) among others, can enhance the use of educational resources for visitors and support personal engagement in learning tasks. Evaluations should provide information about the quality of programmes and information can further inform design processes and professional development. We consider the proposed evaluative framework to provide this information and therefore enhance the educational outcome of programmes and in turn the potential of interactive science exhibitions as educational resources.

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Appendix

The appendix on the following pages are:

Paper-I: Hauan & Kolstø (2014).

Paper-II: Hauan, DeWitt & Kolstø (2015)

Paper-III: Hauan & Hällman (Submitted September 2016)

Paper-I: Hauan & Kolstø (2014).

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Exhibitions as learning environments: a review of empirical research on students' science learning at Natural History Museums, Science Museums and Science Centres

Abstract

One aim for many natural history museums, science museums and science centres is to contribute to school-related learning in science. In this article we review published empirical studies of this challenging area. The review indicates that the effectiveness of educational activities at different types of science-communication venues (SCV) in supporting students' science learning varies. There is also evidence of interesting differences between activities, depending on how these activities are designed. Firstly, these activities can stimulate interest and conceptual focus through a well-designed combination of structure and openness. Secondly, they can stimulate talks and explorations related to the presented topics. We have identified two possible areas which might prove fruitful in guiding further research: an exploration of the effects of different designs for guided exploratory learning, and an evaluation of the effectiveness of educational activities by studying the presence and quality of the learning processes visitors are engaged in.

INTRODUCTION

This review focuses on schools' utilization of exhibitions and educational activities at natural history museums, science museums and science centres (denoted for short as Science Communicating Venues or SCVs) and learning-related experiences provided by visits to such venues. Although we acknowledge that many types of learning outcomes are possible from visits to SCVs, in this review we focus on studies that include findings related to the facilitation of science-concept learning.

In the literature SCVs are often classified together with museums as institutions for informal learning (Hein, 2002). The use of the term informal serves to distinguish these institutions from schools, which are seen as institutions for formal or curricular learning. Rennie (2007) takes up the discussion regarding the words or labels formal and informal, and raises the question “Is there a difference?” (p. 126); she goes on to state that “it does not make sense to try to distinguish it as formal or informal.” (p. 126). Rennie (2007) reminds us that processes of learning are not restricted to certain settings. Guided by the Contextual Model of Learning (CML) (Falk & Dierking, 2000), we will take another approach to the discussion by looking into some factors of the CML which provide insight into how school visit differs from leisure-time visits such as family visits. Several researchers have argued that the SCV visit should support the classroom work (Bamberger & Tal, 2007; Griffin & Symington, 1997; Tal et al., 2005) and that the school curriculum should be used as a basic document for coordinating the activities in these educational arenas (DeWitt & Storksdieck, 2008; Griffin, 2004). The agenda of supporting classroom curricular-based work is linked to both the factors “Motivations and expectations” and “Choice and control” in the CML (Falk & Dierking, 2000 p. 137). This agenda is expressed by most teachers as their main goal with a visit (Anderson & Zhang, 2003; Griffin & Symington, 1997; Kisiel, 2005). Other CML factors are “Within-group sociocultural mediation” and “Facilitated mediation by others” (Falk & Dierking, 2000 p. 137). The mediation within a small group such as a family (Ash, 2003; Rosenthal & Blankman-Hetrick, 2002) differs from the mediation during a school trip where there are many students, few teachers and occasionally no designated staff. The nature of the school visits is shaped by teachers’ agendas and the characteristics of mediation during the school visit. We have therefore chosen to only include studies of school visits in this review.

Several reviews of this field have been published. One is the previously referred to book by Falk and Dierking (2000), in which they present, based on writings within the rich fields of museums and learning, a model that describes how learning is contextualised and identifies key factors which influences in the quality of the museum experience. Another contribution is the article by Pedretti (2002), which takes up the discussion of why and how science centres and science museums should present socio-scientific issues. One of the reviews which deal more specifically with relations between schools and other learning arenas is the previously mentioned article by Rennie (2007), which is a seminal review of literature within the wide area of learning “outside of school”. It discusses major issues within this field and contributes to the discussion by stating: “[…] the value of learning outside of school should be recognized and its benefits harnessed to complement our formal educational programs” (p. 156). In a review of literature on school field trips to “out of school” settings, DeWitt and Storksdieck (2008) state that field trips such as visits to SCVs can be a valuable resource if they are incorporated into classroom teaching, and go on to discuss the influence which the personal, social and physical contexts, teachers’ agendas and the quality of pre- and post-visit material has on the outcomes of the visit. A main claim in their review is that it is necessary to include pre- and post-visit activities at school, and to provide activities which facilitate students’ efforts to link visit-generated primary experiences to classroom work. They also report that teachers’ agendas have a great influence on how the exhibition is utilized and thereby on the educational outcome.

In the present review, based on empirical findings and supported by learning theory, we focus on how SCVs’ exhibitions can be utilized as a learning environment, examining the possible roles of structuring and openness (e.g. no choice versus free choice), and the possible contribution of different activities at SCVs in which the students investigate and talk about science-related topics. The discussion also considers the impact of how the experience is structured, as well as how the given tasks can lead to cognitive activities, thus supporting the processes of learning.

METHOD

The objective of the literature search was to identify empirical studies of school classes’ visits SCV exhibitions, with a focus (partly or solely) on students’ concept learning in science. However, in order to encompass the maximum number of articles, we have not applied criteria for methodologies used. Thus, we have included findings based on end of visit tests, teachers’ impressions, student interviews, analyses of student assignments, questionnaires, concept-maps, and personal-mind-maps, in addition to studies documenting activities and processes believed to characterise productive learning processes. The literature search was initiated using the ISI Web of Knowledge, applying the key words “learning, science, museum”, setting the timespan from 1945 until the end of 2012, with “Education Educational Research” as category and “Article” as document type. The initial number of articles found by ISI was 112; this was reduced to 55 after excluding 25 articles not related to SCVs and 32 articles not related to schools. An investigation of the residual articles revealed that some significant relevant works published in international journals were not listed. The search was therefore expanded by conducting an equivalent search in the databases of the journals Teaching Education and Visitor Studies, and by utilizing Google Scholar to search for articles in the International Journal of Computer-Supported Collaborative Learning, the Journal of Science Teacher Education, the Journal of Computer Assisted Learning, Research in Science Education, Systems and Computers in Japan, and Visitor Studies Today. The initial number of 57 new articles found by this expanded search was reduced to 25 by excluding 24 that were not related to SCVs and 8 not related to schools. These searches resulted in a total of 80 articles. On the basis of the topic for the review, we then excluded 20 non-empirical articles, 2 articles not focusing on science-concept learning, 3 about workshops, 2 about gender issues, 5 about live animal exhibitions, 3 about planetarium shows, 3 about the use of internet unrelated to the SCVs’ exhibitions and 4 about organizing partnership. These exclusions resulted in a set of 38 articles.

The analysis of the identified research studies proceeded in several steps. For each paper, a summary was made focusing on the following elements: research questions and topic, the structure of the visit or how the visit was characterised, student’s age, data collection and methods of analysis, main findings and main claims, and conclusions in the discussion. When several topics and research questions were dealt with in a study, the paper was entered under each relevant topic in a data matrix (Miles & Huberman, 1994) using MS-Excel. All elements in the summaries were entered into the data matrix to provide an overview and facilitate identification of common topics. In the review by DeWitt and Storksdieck (2008), the effects of pre- and post-visit activities are thoroughly discussed. Thus, 9 studies on these subjects were excluded since they did not change the conclusions reached by this previous review. Focusing on the facilitation of student engagement in science learning during visits, two main categories (and several subcategories for facilitating devises) were identified: findings regarding how to facilitate learning at exhibitions and findings regarding how to organise student visits. The associated 29 articles are categorized in table 1.

In interpreting the results in this review, we believe there are two main concerns one needs to be aware of. Firstly, most of the patterns identified are based on relatively few studies. This implies that all results have to be viewed as hypotheses for further research, and as working hypotheses (Cronbach, 1975) for practitioners at SCV. Secondly, although we are well aware that conceptual understanding normally takes time and effort to develop, we set out to identify findings on students’ science learning from SCV-visits. However, few studies have really tried to measure students’ science learning. Many studies have been limited to collecting various actors’ views on students’ learning outcomes, and many studies use general phrases like *educational value*, etc. which need to be more clearly defined. Vague terminology sometimes makes it hard to compare studies and different types of facilitation for learning.

STRUCTURING VISITS

In this section we will examine studies exploring the effects of various forms and levels of structuring in visits to SCVs, exhibitions.

The influence of Structure the Learning Situation

In a seminal study, Bamberger and Tal (2007) identified three different categories of choice with different consequences for students’ actions and learning based on observations and interviews with

Table 1. Articles reviewed and corresponding categories and sub-categories in the review.

Structuring the visit	**Influence of Structuring the Learning Situation**	Bamberger & Tal, 2008, b; Bamberger & Tal, 2007; Cox-Petersen, Marsh, Kisiel & Melber, 2003; DeWitt & Hohenstein, 2010; DeWitt & Hohenstein 2010, b; Griffin, 1994; Griffin & Symington, 1997; Jarvis & Pell, 2005
Facilitating learning in exhibitions	**Characteristics of exhibit design affecting students' learning**	Anderson & Lucas, 1997; Anderson, Lucas, Ginns & Dierking, 2000; Bamberger & Tal, 2008; DeWitt & Osborne, 2010; Falcão et al., 2004; Gilbert & Priest, 1997; Henriksen & Jorde, 2001;Rix & McSorley, 1999; Yoon, Elinich, Wang, Steinmeier, & Tucker, 2012
	Design and effects of worksheets	Griffin & Symington, 1997; Kisiel, 2003; Kisiel, 2007; Mortensen & Smart, 2007; Stavrova & Urhahne, 2010; Rix & McSorley, 1999
	The Use of Narratives	Henriksen & Jorde, 2001; Metz, 2005
	The Use of Technology	DeWitt & Osborne, 2007; Heard, Divall & Johnson, 2000; Hsi, 2003; Hwang, Tsai, Chu, Kinshuk & Chen, 2012; Yatani, Onuma, Sugimoto & Kusunoki, 2004
	Guiding by SCV Staff	Bamberger & Tal, 2007; Cox-Petersen et al., 2003; Stavrova & Urhahne, 2010; Tal, Bamberger & Morag, 2005; Tal & Morag, 2007

10–15 year old students on SCV visits. The first category was *no choice,* which was categorized by strict exhibition guiding, a finding consistent with previous findings by Cox-Petersen et al. (2003). In this visit category, Bamberger and Tal (2007) found that few attempts were made to link the visit to the curriculum or to connect the discussed concepts to the students' previous knowledge or experience. It was concluded that the students' curiosity and eagerness to explore were suppressed. In visits categorised as *limited choice*, students first received an introduction and were then given various kinds of assignments. These assignments engaged the students in content-related talks. More student-teacher and student-guide interactions were observed compared with the no-choice visits. Students made connections on their own to school and non-school related knowledge. It was found that some freedom of choice, combined with exhibition guiding, active teachers and prepared material for the assignments, supported the students in their learning process. However, some students experienced challenges in finishing the tasks. Finally, in visits categorised as *free choice,* the students were free to explore the exhibition as they wished. The students were exited and socialised with their friends, but there was little observed content-related talk. In addition, some students did not see the purpose of interacting with the exhibits and this led to frustration.

Bamberger and Tal (2008, b) investigated the long term effect of a visit to a science museum by 13-16-year-old students, in which the structure combined a guide-directed tour of three exhibitions with free exploration of the same exhibitions. Interviews conducted the day after the visit indicated that most of the students connected the content of the exhibition with their prior school knowledge, and about one third of the students referred to such connections 16 months later. All of the students, whenever interviewed, felt that they had learned by cooperating with peers. Such findings support the view that an intermediate degree of structure has the potential to support social learning.

DeWitt and Hohenstein (2010; 2010, b) conducted observational investigations of school visits to two science museums. The visits were characterized by an open structure in which the 9-12-year-old students selected the topics before the visit, gathered information related to the topics during the visit, and used this material after the visit. The analysis of data from audio recordings and observations of the students indicated that the visits resulted in more balanced discourses between teacher and students, and that students took a more proactive role during the visit than in the classroom (DeWitt & Hohenstein, 2010). The students were more cognitive and affectively engaged during the visit than they were in the classroom, and content-related talk were more frequent (DeWitt & Hohenstein 2010, b).

By analysing worksheets, conducting interviews and observing 10-16-year-old students and their teachers in connection with visits to two venues in Sydney (Griffin, 1994; Griffin & Symington, 1997), it was found that differences in agendas (learning oriented, task oriented or neither) and types of student tasks influenced the structure of visits. Interviews with students during and after the visits revealed that the students had clear preferences regarding the structure of the visits; they wanted to be able to influence the execution of the visit, to be sure that the educational activities supported their school work and to work in groups (Griffin & Symington, 1997).

In a qualitative investigation of visits to the UK Space Centre, Jarvis and Pell (2005) found that providing structure via a combination of focused and manageable tasks and of facilitative support by adults was a successful strategy for creating interest and reducing anxiety about science. This indicates that young students can benefit from adult guidance to help them to choose from the wide range of offered experiences.

With regard to students' reactions to different types of structuring, the studies reviewed indicate the following: A *no-choice* structure might ensure a focus on predefined concepts and activities but suppress eagerness to explore, and might not lead to content-related talk; *free choice* might stimulate excitement, but little content related talk, and can result in frustration. *Limited choice* can reduce anxiety, and stimulate interest and student-teacher interactions although it may generate challenges in ensuring progress in the completion the educational tasks (Bamberger & Tal, 2007). On the other hand, appropriately designed tasks (including worksheets) can increase such progress. Limited-choice structuring involving opportunities for self-governed exploration and cooperation also seem to encourage content-related talk among students with the potential to enhance the learning outcomes of the visit (Bamberger & Tal, 2007; DeWitt & Hohenstein, 2010, b).

Facilitating learning in exhibitions

An SCV consists of exhibits typically designed as standalone units and designed to communicate one or several science-related topics. The core purpose of the exhibits and the venue as a whole is, apart from stimulating interest, to support learning (Falk & Dierking, 2000; Lord, 2001). Moreover, the findings presented in DeWitt and Storksdieck's (2008) review indicates that this purpose is reflected in many teachers' beliefs and agendas for SCV visits. In this section, we will consider findings from studies that have explored exhibits as learning material, as well as the methods used to support the intended learning outcome of a single exhibit or the intended learning outcomes of several exhibits grouped together within a theme.

Characteristics of exhibit design affecting students' learning

A key element which can affect students' learning from a SCV visit is the design of the exhibits themselves.

In a study using concept maps and interviews of 11-12-year-old students, Anderson et al. (2000) found that the conceptual understandings the students developed from interacting with an exhibit were dependent on how the phenomena were presented in the design and by the labels; and that the students' interpretations of their observations were influenced by their previous experiences. For instance, an exhibit that was designed to illustrate how magnetism is changed by extreme heat was misinterpreted and resulted in misunderstandings related to how magnets work.

Similarly, Henriksen & Jorde (2001) found that complex exhibits designed to communicate the topic of radiation and health were often misunderstood by high school students; and that the students did not always utilize the information provided the way the designer had intended.

Falcão et al. (2004) interviewed 9-16-year-old students to determine their understanding of the complex relation between the sun, the moon and the earth after they had visited an exhibition on that topic. They concluded that the student's conceptual understanding of complex topics was optimized by combining exhibits presenting composite phenomena with exhibits focusing on only one phenomenon.

By analysing students' answers to post-test questionnaires, Anderson and Lucas (1997) identified some design properties that influenced the potential of the exhibit as educational material. They found that physically large, interactive exhibits that are highlighted in the exhibition are more often discovered, used and recalled by the 13-14-year-old students, and are therefore more likely to support learning. In addition, in a qualitative study Gilbert and Priest (1997) found that the ability of 8-9-year-old students to recognize an exhibit as being familiar was critical in initiating a discussion with fellow visitors on a related topic. For this discourse to continue, it was essential that the exhibit somehow enabled the visitors to identify some links to their everyday lives.

Rix and McSorley (1999) investigated young children interacting with exhibits in a small school-based museum. They found that, although young children often seemed to be playing randomly with exhibits, the exhibits with changeable elements were utilised for systematic exploration. Many students also used scientific terms and expressions, and some tried to explain their observations in such terms. They concluded that, although the exhibits were not necessarily used as intended by the designers, the children's playful exploration could be characterized as scientific work. These finding are echoed by DeWitt and Osborne (2010), who found that many science-centre exhibits generated playful exploration. They also revealed several significant exhibit design factors for engaging the 9-11-year-old students: hands-on interaction, multiple opportunities for exploration and collaboration, and phenomena that contrasted with previous experiences or that were perceived as cognitively challenging. Based on their findings from observations of students during museum visits and semi-structured follow-up interviews, Bamberger and Tal (2008) add the design principle that exhibits should be designed to facilitate discussions.

A study by Yoon et al. (2012) investigated the effect of adding digital visualisation and directed questions to an existing exhibit as design elements. Observations and interviews with 12-14-year-old students did not reveal significant changes in conceptual learning gains; however, there were indications of increased skill in theorizing about the phenomenon.

These studies indicate that certain characteristics of an exhibit, such as size, interactivity, supporting visualisations, questions and possible links to everyday life, may increase visitors' use, discussions, theorizing, recall and probably also science-concept learning. Moreover, exhibits enabling interaction may lead to unintended use involving playful exploration and hypothesis testing resulting in attempts to explain using scientific terms. Another important finding was that students' interaction with exhibits can generate other but accepted cognitive understandings (Anderson et al. 2000; Henriksen & Jorde, 2001, Rix & McSorley, 1999). There are also indications that exhibits that are complex and dependent on the users having sufficient background knowledge can be misunderstood more easily, risking alternative conceptual understandings. The findings by Falcão et al. (2004) indicate that the challenge of complexity can be overcome by designing a cluster of exhibits that present different elements of the subject matter. Nevertheless, studies on the influence of design on students' learning are few, and need to be interpreted with care.

Design and effects of worksheets

Although some research has found that worksheets utilized in an SCV can lead to a narrowing of focus towards 'finding the right answer' and that students often consider worksheets dull (Griffin & Symington, 1997; Rix & McSorley, 1999), more recent research has emphasised that the type of worksheet matters.

Kisiel (2003) interviewed teachers who have developed such worksheets. He found that they viewed worksheets as critical for keeping students focused and for leading them through the planned educational activities. He also identified two main agendas underpinning the design of worksheets. Worksheets based on a *survey agenda* were intended to provide students with an overview of much of the museum and involved activities such as collecting facts, reading and copying text from exhibition labels. Those based on a *concept agenda* were consistent with a particular conceptual learning goal and placed greater emphasis on observations rather than label reading. However, concept-agenda worksheets typically had little information regarding where the answers could be found, which was confusing and distracting for some students.

In another study, Mortensen and Smart (2007) investigated the use of Chaperone's Guides, a type of worksheet designed to facilitate group dialogue. These were developed in an attempt to encourage some free-choice learning while meeting teachers' requirements for content connected to the curriculum. Observations and analysis of conversations that occurred during the visit indicated that the guides increased the conversations related to the intended curricular learning outcome. However, while some of the 8-11-year-old students preferred the open ended questions that allowed for different ways of approaching the subject, others were frustrated by the same tasks and preferred closed questions with only one correct answer.

In another study, Stavrova & Urhahne (2010) investigated a redesign of an educational activity at the Deutsches Museum. The redesign involved, among other elements, changes to worksheets, in which the open questions of the previous worksheets were replaced by multiple-choice questions in which the right answers led to a solution word. The studied 13-16-year-old students were given points for the right solution words and a winner was declared. Findings suggest that the redesign of the worksheets had a positive influence on the students' attitudes and understanding of topics covered in exhibitions.

In a study, Kisiel (2007) asked teachers to examine one *survey agenda* worksheet and one *concept agenda* worksheet designed for a trip to a natural history museum. 60% of the teachers preferred a *survey agenda* for a visit with 4th and 5th grade students, while 70% preferred it for 7th and 8th grade students. Some of the most significant rationales given by the teachers for their choice were high task density, directedness, level of difficulty, relevance, question format and cognitive level. None of the teachers gave curriculum connection as the rationale for their choice. Moreover, there were some cases of lack of coherence in teachers' preferences; for example, while some teachers chose the *survey agenda* type because of its high task density, others rejected this type for the same reason. Only one correlation was found to be consistent: teachers who focused on task relevance for the students preferred the concept-oriented worksheets. They stated that this type was more enjoyable and provided a more meaningful learning experience.

Findings related to the possible role of worksheets in stimulating and facilitating learning depict a complex picture. Mortensen & Smart (2007) have documented how worksheets can be designed so that the rate of curriculum-related group dialogues increases, thus potentially supporting learning. However, worksheets with other characteristics can result in an emphasis on completion and reduced focus on learning, and some students consider worksheets boring (e.g. Griffin & Symington, 1997).

The Use of Narratives

Henriksen & Jorde (2001) presented students with a narrative in the form of a "real life" story which was designed to serve as a common thread through the SCV visit phases: the preparation, the visit to a technical museum and the post-visit reflection. Based on a comparison of pre- and post-texts, the researchers concluded that the high school students' written language became less personal and more scientific.

To investigate narratives as a way to create a stimulating context for SCV experiences and support learning from them, Metz (2005) studied a teacher-student programme at a historical museum where science was conveyed by using role-play and historical exhibits as props in a story about how the exhibited objects were used. They found that students' preparation for and participation in a performance served as an engaging learning activity.

Although only two articles were found on the use of narratives and their influence on learning, the findings indicate that narrative is a promising instrument for facilitating engagement and science learning. A common characteristic of these two studies seems to be the use of narratives to help students stay focused, while at the same time allowing for personal choices and actions within the narrative frame. Some non-empirical studies have argued the need to explore the use of narratives further. Rounds (2002) views narratives as a means to elucidate the relationship between science and society. Bedford (2001) adds that the use of narratives coincides with everyday learning and that this probably implies that remembering is facilitated.

The Use of Technology

Technology has often been advocated as a way of supporting learning from SCV visits.

In one study, Heard et al. (2000) investigated the utilization of audio-guides as a tool to increase the learning of 9-11-year-old students from exhibit interaction. The auditory commentary led the user through different experiments and described generally expected results. Questionnaires measuring knowledge of pendulums reflected that girls improved their knowledge by roughly 100% and boys 25% when they used the audio guides. Corresponding values for the control group, however, were a 5% increase among girls but 50% among boys.

In a study by Hsi (2003), users were equipped with PDAs, including an ear-plug, which provided additional information about exhibits, suggestions for interactions and explanations to phenomena. The system also recorded the students' experiences on a personalized web site for later recapture and reflection. Most of the users liked the system and it seemed to encourage new ways of playing with the exhibits. However, some users, including teachers, reported a negative impact in that it created a feeling of isolation from social interaction and restricted explorative behaviour.

In another study, Yatani et al. (2004) conducted research on the utilization of a computer-based network system and PDAs to present multiple-choice questionnaires to users. Answers to the questions could be found by interacting with the exhibits and by reading the explanatory texts. They found that 94% of visiting 6-12-year-old students enjoyed using the system and 84% believed that it facilitated their learning. It was also found that the intended increase in attention compared to less used exhibits was achieved.

In a more straightforward use of technology, students visiting a science museum were asked to take photographs, write notes and use this as material for generating a post-visit presentation. Data analyses of the behaviours of observed 9-10-year-old student indicates that the post-visit presentation assignment fostered cognitive engagement during the visit and fruitful discussions during the post-visit production (DeWitt & Osborne, 2007).

In their study, Hwang et al. (2012) compared the learning outcome for 10-11-year-old students who completed PDA-guided inquiry-based tasks linked to exhibits, with those of students who completed similar task that were teacher-guided. The post-tests showed highest achievement scores for those students who were lead through the processes of scientific inquiry by the user controlled instructions incorporated in the PDA.

The reported findings indicate that the use of PDAs and multimedia phones has the potential to increase the time spent on exhibitions, to support students' conceptual learning and to make exhibitions more memorable. However, there are also indications that PDA's can restrict visitors' exploration. The study by Hwang et al. (2012) indicates that technology can be used in educational activities designed to increase students' explorative behaviour.

Guiding by SCV Staff

Many SCVs employ staff to facilitate or scaffold students' learning from SCV visits.

Observations of guided tours at a natural history museum lead Cox-Petersen et al. (2003) to conclude that guiding at the different exhibitions mainly followed a prepared script that was not adjusted to students' previous knowledge and focused on facts rather than ideas or concepts. Moreover, most guides relied mainly upon closed questions to stimulate interaction. Measured learning outcomes detected few cases of conceptual learning. Most of the teachers and the 7-14-year-old students expressed their appreciation of the guided tours and considered them to be a fruitful learning experience. However, about half of the teachers suggested that the guiding should be less structured and more specifically linked to students' previous knowledge and interests.

In order to investigate the teachers' role and perceptions related to SCV visits, Tal et al. (2005) studied educational activities offered by four natural history museums in Israel. These activities utilised various methods of dissemination, such as instructional talks, tours in the exhibition, demonstrations, games, and worksheets. Most of the teachers approved of the methods used by the guides to support learning. However, they also expressed their concerns about too much lecturing, irrelevant movies, too few links to the students' previous knowledge and too little time for free-choice investigation (Tal et al., 2005).

In their analysis of observations and interviews with students from primary, middle and high school students in connection with visits to science and national history museums, Bamberger and Tal (2007), and Tal and Morag (2007) found similar issues when the educational activities were tightly controlled by a guide. On such guided tours, there were very few attempts to connect the content to the students' previous knowledge or interests. Tal and Morag (2007) found very few attempts to challenge the students to express their own thoughts. Bamberger and Tal (2007) argue that tightly controlled activities may suppress students' motivation for further exploration.

The effects of redesigning a guided visit were investigated by Stavrova and Urhahne (2010) in a mixed-method qualitative and quantitative study. The guided tour in a new energy exhibition was changed so that the dominant unidirectional communication was replaced by dialogical communication between the staff and the 13-16-year-old students. The guides presented questions and some alternative answers to these; they then commented on each student group's choice of answer. The findings indicate that this modification meant that the students were less bored and more motivated.

The above-mentioned findings (Bamberger & Tal, 2007; Cox-Petersen et al., 2003; Stavrova & Urhahne, 2010; Tal et al., 2005; Tal & Morag, 2007) suggest that communication by staff can be unidirectional and involve closed questions, and that few attempts were made to link or adjust the material to suit students' previous knowledge or interests. The structure of some of the studied visits also offered few opportunities for free-choice exploration and were not flexible in terms of adjusting to requests and inputs from students. Moreover, the learning outcome was often found to be rather low, and facts were usually in focus rather than ideas.

However, the findings of Stavrova and Urhahne (2010) show the possibility of shifting from monologues towards more dialogue-oriented communication. Thus, the question does not seem to be whether or not guided tours support learning, but how guided tours might be designed to increase students' engagement and learning.

Discussion

This review suggests that the effectiveness of SCV educational activities in supporting students' science learning is variable. However, interesting differences between activities have been revealed, and these differences are not between the use of worksheets, narratives, PDA-technology or staff, but rather between the ways such resources are designed and used. We have identified two possible areas for research which may prove fruitful in taking research on science learning in SCV a step further: The effects of different designs on *guided exploratory learning*; and the evaluation of the effectiveness of educational activities, designs and activities by studying the presence and quality of the *learning processes* the visitors are engaged in.

Level of structuring

Utilizing SCV exhibitions for curricular learning implies guiding students towards specific educational goals determined by the teacher or SCV-staff, not by the student. Such guidance – whether it is achieved through the use of worksheets, PDAs, narratives or SCV staff – implies challenging the view that an exhibition as an arena for free-choice learning (Falk & Dierking, 2000 p.xii). However, if curriculum-related science learning is taken as an aim, the question becomes how learning can be supported within a context that involves students' use of SCV-exhibits. In their study of structure, Bamberger and Tal (2007) found that students enjoy free exploration of an exhibition. However, they also found that free exploration can create frustration and, more importantly, that this lack of structure generated little learning-related behaviour. Other research suggests that appropriate structure and guidance can lead to increases in interest (Jarvis & Pell, 2005), as also previously found by Rennie (1994). Finally, visits that are too strictly controlled can be counterproductive for learning, by restricting students' learning-related behaviour (Bamberger & Tal, 2007; Griffin & Symington, 1997; Heard et al., 2000; Hsi, 2003; Kisiel, 2007; Rix & McSorley, 1999).

One possible interpretation of these findings is that SCV educational activities should provide both freedom of choice and structure to facilitate both personal motivation and focus on relevant activities, observations and concepts. The need for structure and rules to provide focus is also supported by Csikszentmihalyi and Hermanson (1995), who claims that educational activities that facilitate curiosity and interest are characterized by having "*clear goals and appropriate rules*" (p.36). Dewey (1938) adds to this perspective by reminding us that "*without rules there is no game*" (p.52) – and games allow for exploration and playful action. This indicates that the apparent conflict between guidance and free choice, and the need to balance these, may have an alternative solution. Similarly, we believe that evidence from research on structure indicates that SCV visits can be designed to provide both freedom of choice and structure. We believe that this idea, which may be denoted as *guided exploratory learning*, is congruent with the view held by Bamberger and Tal (2007), who concluded that "activities in museums that allow controlled choice are most suitable" (Bamberger & Tal, 2007).

One example of how this might be practically implemented involves the use of worksheets, which are generally regarded by teachers as appropriate tools for structuring a visit (Kisiel, 2003). It has been found that worksheets with closed tasks can reduce students' motivation (Griffin & Symington, 1997), restrict exploratory behaviour (Rix & McSorley, 1999) or focus students' attention primarily to the label text of the exhibits (Kisiel, 2003). However, worksheets with open-ended tasks have been found to generate open discussions and are preferred by some students (Mortensen & Smart, 2007). Such worksheets are also considered by some teachers to be more enjoyable for the students and to generate more meaningful learning experiences than worksheets with closed tasks (Kisiel, 2007). These findings indicate that worksheets with open questions can facilitate some degree of free-choice exploration, yet within boundaries. How to design worksheets that provide for both freedom of exploration and necessary guidance should continue to be an area for further research.

Bamberger and Tal's (2007) categories *free*, *limited* and *open choice* denoting levels of structure seem to be valid and useful for the analysis of visits. Kisiel (2003) and Griffin & Symington (1997) add to this categorisation when they find that design of worksheets for different purposes for example, to stimulate students to survey the SCV, to complete tasks or to focus on specific scientific concepts – impose different categories of visit structures.

Studies by Griffin and Symington (1997), Mortensen and Smart (2007) and Cox-Petersen et al. (2003) send a mixed message about teachers' and students' preferences for different levels of structuring. Some teachers and students prefer that students have considerable choice in determining how the visit will proceed, while others prefer greater structure and curriculum relevance. One might hypothesise that the various preferences may be due to different views about teaching and learning, and different anticipated outcomes of the visit.

The use of narratives reported by Metz (2005) implies using a narrative and an open-ended task to guide exploratory learning. While the task demands structured preparation for a performance within the boundaries of the given context, it also involves playful activities within "the rules of the game".

PDAs and other transportable ICT-equipment could also be used in *guided exploratory learning* since they allow for some free choice by enabling the students to control the guidance provided by the equipment (Heard et al., 2000) or to expand the degree of freedom by pointing to more ways of using an exhibit (Hsi, 2003). However, findings indicate that audio-based technology can restrict exploratory behaviour (Heard et al., 2000; His, 2003), and social interaction (His, 2003). The multi-modality of PDAs and multimedia-phones provide a wide range of features which paper-based worksheets do not have, and research regarding how to utilize these features in order to provide students with both structure and openness in the visit seems to be desirable.

Facilitating explorative processes important for science-concept learning

The studies reviewed in this paper have made use of a range of methods for gathering information on students' learning. In particular, learning has been identified by analysing observations of students during visits to SCVs, concept maps and written texts produced by students, students' responses on questionnaires and in interviews, and students' and teachers' opinions regarding students' learning. The documented effects of these visits on students' learning vary, often being less than hoped for. However, this should not come as a surprise. Concept learning normally take time, and to measure changes in conceptual understanding after a few hours of exhibition guiding, task completion and playful interaction seems both demanding and inappropriate (Allen, 2002; Dierking, Falk, Rennie, Anderson & Ellenbogen, 2003). An example of these difficulties is the documented development of new alternative concepts among some students during SCV visits. Such development or reinforcement of misconceptions is also found in studies involving leisure-time visitors to SCVs (e.g. Stocklmayer & Gilbert, 2002). This challenge is in accordance with Novak's (2002) review of research on concept learning, in which he shows how weak prior knowledge can result in increases in misconceptions. One way to combat this development is to include pre- and post- visit activities. However, if changes in understanding are measured across the whole learning period, it is difficult to isolate the contribution of SCV visits to students' learning, compared with the contribution of pre- and post-visit activity. Nevertheless, if we agree that the ideal is to include pre- and post-visit activities (DeWitt & Storksdieck, 2008), this discussion about possible sources of effects becomes less relevant.

Another approach, which we suggest, is to focus on explorative processes believed to be fruitful for learning. Today, it is widely acknowledged that conceptual learning in science is dependent on the student's active mental and verbal involvement, and to the linking of concepts to observations, experiences and prior knowledge (e.g. Ausubel, Novak & Hanesian 1978). Concept learning involves the exploration and identification of possibly relevant prior knowledge, in order to provide anchor points for new ideas and prepare for restructuring (Novak, 2002). However, it also involves the active exploration of experiments and observations, the generation and exploration of possible interpretations of observations and the exploration of possible ways to understand and talk about experiences and observations using everyday language and science concepts. These explorative processes are fuelled by the inputs and guidance of more knowledgeable supervisors (Vygotsky, 1986) or texts (Coxall, 1994) All these explorative processes involve the learner's active use of language, whether inner speech or oral and written discussion (Vygotsky, 1986). For some individuals, learning based on reading, quiet observation and inner dialogic speech is fruitful, while for others this approach is overly taxing and counterproductive (Dunn, 1984; Gardner, 2006). One possibility, therefore, is to study the presence and quality of different explorative processes involving practical experiences, testing and observation and explorative conversations and writing during SCV visits with different types of educational activities. This process perspective may facilitate the documentation of fruitful learning processes that are going on at SCVs, even when high scores on tests on concept learning are irrelevant or hard to achieve.

The present review indicates that this approach to researching school trips can be workable and fruitful since several studies have shown how certain ways of designing the roles of staff or teachers may result in dialogic communication with students (Bamberger and Tal, 2007; DeWitt and Hohenstein, 2010, a; DeWitt and Hohenstein, 2010, b; Stavrova and Urhahne, 2010). Some studies have documented how it is possible to engage students in content-related talk, and how this may have been triggered by the familiarity of the topic of an exhibit (Gilbert & Priest, 1997), stimuli in a worksheet (Mortensen & Smart, 2007), interesting observations at exhibits (DeWitt & Osborne, 2010; Rix & McSorley, 1999) and pair work towards a common goal (DeWitt and Hohenstein, 2010, b). Moreover, Bamberger and Tal (2008) found that students felt that cooperating with peers contributed to their learning. Other studies have shown that wisely designed exhibits support students' learning (Anderson & Lucas, 1997; Gilbert & Priest, 1997) and trigger testing of hypotheses (Rix & McSorley, 1999). In addition, the relevance of reading labels (Yatani et al., 2004) and recording findings on worksheets (DeWitt & Osborne, 2007) have been documented in situations characterised by elements of choice within a focused but motivating structure. On the other hand, the review also presents a range of studies which indicate that not all uses of worksheets, PDAs and staff lead to the desired amount of participation, exploration, content-related conversations and label reading (e.g. Cox-Petersen et al., 2003; Griffin & Symington, 1997; His, 2003). However, in these studies it seems less clear which characteristics of the physical exploration process can be regarded as relevant for concept development. Further research regarding the quality of different types of physical exploration in relation to science concept learning seems needed here.

Future research with a conscious and explicit focus on the presence and quality of relevant explorative processes may make it possible to better judge the learning potential of the SCV-visit. This view is supported by Rennie, Feher, Dierking & Falk (2003), by stating that *"learning is both a process and a product so we need to investigate the processes of learning as well as the products*" (p.116).

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