Comparing Materials for Self-Guided Learning in Interactive Science Exhibitions

Nils Petter Hauan[1] and Jennifer DeWitt[2]

[1]Bergen Science Centre, Bergen, Norway

[2]UCL Institute of Education, London, UK

Nils Petter Hauan, Ph.D., is Head of Development at VilVite the Bergen Science Centre, Norway. His research interests include interactive science exhibitions and, in particular, the potential of such exhibits as educational material for schools. Send correspondence to: Nils Petter Hauan, VilVite, Bergen Science Centre, Thormøhlens gate 51, 5006 Bergen, Norway. Email: nph@vilvite.no.

Jennifer DeWitt is a Senior Research Associate at UCL Institute of Education, focusing on nationwide longitudinal studies examining the development of children's interests and aspirations in science, as well as the implications of research on science capital for practice in schools and informal settings. Her broader research and evaluation interests include learning and engagement in early years, families, and school groups in informal science environments, including the potential of makerspaces as tools for equity. Email: j.dewitt@ucl.ac.uk.

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Abstract

Science center exhibitions are considered to have the potential to support students' learning. To contribute to the field's knowledge of how to utilize this potential to the fullest, this study compares four different designs of self-guided resources for use during a science center visit. The first two (open exploration and a traditional worksheet) are similar to many currently in use, and the other two designs (guided exploratory learning, one paper-based and one tablet-based) provided more structure and explicitly aimed to support deeper engagement and exploration. Verbal and non-verbal behaviors of 64 11- to 13-year-old students were recorded by chest-mounted cameras. Video was coded and analyzed quantitatively around instances of behaviors consistent with deep engagement and learning. Findings suggest that different resource designs are associated with different levels of engagement-related behaviors, and designs for guided exploratory learning in particular have the potential to support students' progress towards conceptual understanding.

Interactive exhibitions, such as those in science centers, may support students in their progress toward conceptual understanding in the sciences (e.g., Hauan & Kolstø, 2014; Kisiel, 2013; Rennie, Feher, Dierking, & Falk, 2003). Numerous research studies have investigated the effect of structures and materials that aim to fulfill exhibitions' educational potential. Some of these have taken a user preference perspective. For example, Kisiel (2003, 2007) investigated teachers' perspectives and found that some teachers preferred worksheets that encouraged students to collect facts, arguing that this format kept the students focused, whereas other teachers preferred a more open-ended design because it led to more enjoyable and meaningful experiences. Mortensen and Smart (2007) also found variation in preferences, noting that preferences for open or closed questions varied among students.

Other studies have investigated how structures and materials affect student behavior. For instance, Bamberger and Tal (2007) report that students enjoyed an open structure that enabled them to explore freely, but this structure resulted in little content-related talk, superficial interactions with exhibits, and minimal label reading.

Focusing more on materials, traditional worksheets, with closed questions and an emphasis on locating and writing correct answers, have been found to be disliked by students and rarely completed (Griffin & Symington, 1997; Rix & McSorley, 1999). Other research has investigated materials that aim to guide students' exploration in a way that facilitates learning behaviors beyond simply reading and writing. For instance, the use of appropriately designed multiple-choice questions can positively influence students' engagement and task involvement (Stavrova & Uhrane, 2010). Others argue that worksheets can be designed in ways that result in content-related group dialogue, which facilitates sharing and responding to thoughts and ideas (Mortensen & Smart, 2007).

Other studies have investigated use of digital technology to guide exploration on school trips. Findings suggest that the use of Personal Digital Assistants can improve student engagement (Hsi, 2003; Yatani, Onuma, Sugimoto, & Kusunoki, 2004) and learning outcomes (Hwang, Tsai, Chu, Kinshuk, & Chen, 2012.) Other research found that an educational intervention designed as a game-based narrative for mobile phones generated learning-related verbal and non-verbal behaviors and engaged students in a joyful way (Kahr-Højland, 2010).

The studies presented above indicate that materials designed to guide students' exploration may support learning-related behaviors more effectively than open exploration (no guiding material) or traditional worksheets. They also suggest that the use of digital technology can improve students' exploration and engagement. However, because these studies were conducted in a variety of contexts and countries with different ages of students, it is difficult to draw general conclusions and gain insight into the design of materials for self-guided school trips. We consider therefore that a comparative study of design principles within a single context could provide some useful insight. Our current work attempts to do so and, thus, contribute usefully to the debate by testing four designs for use with a set of five exhibits in one science center with groups of students of similar ages (11 to 13).

Conceptual Framework

This study focuses on possible effects of various handout designs on students' behavior during school trips, rather than on individual students' learning outcomes. We begin by outlining the rationale for focusing on behaviors indicative of overall engagement as well as deeper engagement in the learning environment. Next, we summarize the conceptual underpinnings of the design principles we used to elicit and encourage these desired behaviors.

Facilitating overall engagement in the learning environment. Within the vast literature on teaching and learning, the concept of transfer is often defined as the ability to use previous learning in new situations (e.g., Gick & Holyoak, 1983). Bransford and Schwartz

(1999) argue for a broader perspective on transfer by considering it as the ability to transfer the experience of learning in one situation to learning in new situations. They use the term Preparation for Future Learning (PFL) to denote this view of transfer (Bransford & Schwartz, 1999, p. 68). Watson (2010) adopted this perspective in a study of school trips to a science museum. Through pre- and post-testing, he found that engagement in a learning environment, where students experienced phenomena and read content-related texts, increased the learning outcomes from a follow-up session (back in the classroom) that addressed related scientific concepts. He argues that involvement in learning environments, including interactive exhibitions, can support PFL. The learning environment encountered by students in the present study has similar features to those in Watson’s study (and in many science centers). This similarity suggests that engagement in the current learning environment may likewise lead to PFL. Consequently, in the present study, we investigate the relationship between various types of handouts and overall engagement in a learning environment, an experience that has the potential to support PFL.

As Tiberghien (2000) reminds us, students' learning environment "includes all human and material resources in the situation" (p. 31). To analyze overall engagement in the environment, then, we investigate the presence or absence of students’ activity involving the following educational resources: (a) interactive exhibits, (b) text, and (c) peer group interactions. Interactive exhibits allow a student to explore phenomena and to observe others' exploration. We include others' activity because previous research in areas as disparate as learning from school trips (Watson, 2010) and neuroscience (Tokuhama-Espinosa, 2010) suggests that observation of peers having visible sensory experiences can have a similar effect on the observer. Text (e.g., labels) present scientific concepts that may be read directly or listened to (from others’ reading). Finally, because the manner in which group work is organized (e.g., to encourage cooperation) can influence learning outcomes (Johnson,

Johnson, Stanne, & Garibaldi, 1990), we include a focus on peer group organization and student participation. These areas of activity provide an overview of students' general engagement in the learning environment.

Facilitating deep engagement. Although overall engagement is important, we also wanted to go further, to see if—via handout materials—we could encourage more of the kinds of behaviors that research has found to support learning. A long tradition of previous research has highlighted the critical role that social interactions play in learning (e.g., Vygotsky, 1978, 1986). More recently, Mercer (2000) used the term *interthinking* to describe "co-ordinated intellectual activity which people regularly accomplish using language" (p. 16). A related perspective is presented by Roth and Jornet (2014), who argue that experience is a category of thinking that should be analyzed by considering the individuals, the learning material available to them, and the social setting as a whole.

Moreover, interactions that support learning do not only occur among people but with a range of elements. More specifically, in the context of this research and in accordance with Wertsch (1991), we believe that exhibits, scientific texts, students and teachers, and students' prior knowledge can be viewed as elements of a tool kit of educational resources that define a learning environment. The verbal and non-verbal behaviors that are generated during activities related to these educational resources are indicators of exploratory experiences in which students' conceptual propositions are developed, presented, and tested in a social environment.

Finally, in line with Ausubel et al. (1978) and Bransford et al. (2000) we consider learning from any experience to be highly influenced by an individual's prior experiences. Therefore, behaviors that indicate that students are linking the visit experience to previous experiences formed an additional focus of analysis.

Design for guided exploratory learning. As with other work (e.g., Barriault & Pearson, 2010; Humphrey & Gutwill 2005), our focus ultimately is on learning from interacting with hands-on science center exhibits, and we aim to promote deeper levels of engagement in these experiences. However, rather than focusing on elements of the exhibits themselves and how they might be designed to encourage particular desired interactions and behaviors, we focus on handouts, or materials that students might use during a school trip. More specifically, drawing on the conceptual framing outlined above, in our previous work we began to articulate a set of design principles that, if implemented, might have the potential to elicit behavior consistent with overall and deeper levels of engagement. Fundamentally, these design principles—which together we term *Guided Exploratory Learning* (GEL) design—are rooted in research on practical work (Millar, 2004). We took this approach because we see parallels between practical work in the science classroom and the observation and manipulation of objects and phenomena in interactive science center exhibits.

Millar (2004) argued that the objective of practical work is to support students to understand scientific concepts by providing experiences that link the real world with abstract ideas. Likewise, Tiberghien (2000) asserted that for such experiences to result in linking, they should relate to students' prior experiences and involve communication—sharing understanding and responding to others' understanding. In line with these researchers, we contend that to support linking the real world with abstract ideas, practical work should involve four principal elements: (a) Exploration of phenomena through direct sensory experience (Piaget 1935, 1965) and observation of responses to one's own activity (Dewey, 1997); (b) Sensory perception of concepts via phenomena presented in a meaningful context (Sutton, 1992) to ensure that scientific models (or ideas) are in play during the activity (Abrahams & Millar, 2008); (c) Linking to everyday life to facilitate anchorage to prior experiences (Ausubel, 2000); and (d) Group work in which different ideas and understandings can be explored (Dewey, 2011) and tested via interactions with others (Vygotsky, 1986). Consequently, these four elements—which resonate with behaviors consistent with deep engagement—form the underlying principles of GEL design which, in turn, aims to support student engagement in a science center context.

In the pilot study for our current work, we built upon this conceptual framing to identify and operationalize learning behaviors that might be observed on school trips supported by self-guided materials (Hauan, DeWitt & Kolstø, 2015). More specifically, we identified verbal and non-verbal behaviors that indicate deeper engagement within the learning environment, which we termed *Multi-Modal Discussions* (MMD*)*. In the present study, we investigate the way in which four handout designs engage students and contribute to MMD.

In sum, this study aimed to increase understanding of how the design of materials for self-guided trips may enhance the quality of students' learning experience in science center exhibitions. The designs we investigated had similar introductions and final summarizing tasks and involved the same set of exhibits. Drawing on previous research (e.g., Hauan & Kolstø, 2014; Rennie et al., 2003), we attempted to gauge the quality of resources provided to students from a process perspective. That is, we focused on students' behaviors as they worked with the resources rather than attempting to assess learning outcomes. By analyzing video-recorded behaviors, we aimed to address the following research question:

> How do differences in resource design relate to learning-related behaviors observed on school trips to a science center? In particular, as students utilize different handout designs, what levels of engagement are seen overall, and are the observed behaviors consistent with multi-modal discussions?

Method

This study forms part of a larger project that addresses the issue of enhancing the educational quality of school visits to interactive science center exhibitions. A previous review (Hauan & Kolstø, 2014) highlighted a need to develop principles for guiding students' exploration in these settings and a need to refine evaluation methods based on the learning processes students are engaged in. A more recent study (Hauan et al., 2015), resulted in a proposed framework for a process perspective on evaluating the quality of materials (such as worksheets) that guide exploration. The analysis in the current study is based on the framework proposed previously, which is used to evaluate the quality of four versions of educational materials designed to guide students' activity on a school trip. Fourteen classes of Norwegian primary school[1] students in grades six and seven (11-13-year-olds) participated in the study.

Exhibits

In this study, we compare four handout designs. All four focus on energy-related concepts such as the way in which electric energy is generated by transformation from other forms of energy. The resources were developed to structure the visits as an exhibition-based learning path (i.e., supporting student' interactions with a specific set of exhibits, emphasizing a particular topic). The four handouts involve the same five focal interactive exhibits, presented in Table 1.

Table 1

Focal exhibits (explored by all groups)

Exhibit name and instructions	Concepts addressed
Solar Plane Direct the light to solar panels to power the planes.	Current generation by photon absorption
Wind Bike Use the pedals to activate a fan and generate wind for a wind turbine that powers light bulbs.	Energy transfer, Kinetic energy
Generator Power the light bulb by moving the magnets past the coils by hand.	Current generation by induction
Water Power Use a pedal to rotate the pumps that lift water to the reservoirs. Guide the water to a turbine to power the light bulbs.	Force, Mechanical work, Potential energy
Carbon Catcher Experiment with a gas power plant model with gas turbines and fuel cells and test different gas treatment processes.	Fossil fuel, Thermal energy, Chemical energy, Combustion

Handouts

The four handout designs investigated in this study are termed Open Exploration, Traditional Worksheet, Paper-based Guided Exploratory Learning (P-GEL), and Digitally presented Guided Exploratory Learning (D-GEL). They were developed to correspond broadly to types of worksheets or guidance (both paper-based and digital) explored in previous research on school trips (Bamberger & Tal, 2007; Griffin & Symington, 1997; Hwang et al., 2012; Mortensen & Smart, 2007). All four designs have colorful images and texts, and a map indicating where the relevant exhibits can be found. The Open Exploration resource depicts exhibits and their names. The instructional text broadly encourages students to explore the exhibits and discover what they are designed to convey. The Traditional Worksheet resource presents pictures of the exhibits and directs students to write answers to specific questions. This sheet's text also includes the theme of the exhibit, directions for operation, and the names of focal concepts. Both P-GEL and D-GEL designs aim to scaffold students' learning by guiding their interaction with various elements in the learning environment, similar to utilizing the potential of practical work (Millar, 2004). Both GEL designs have illustrations of how focal concepts may be encountered in everyday life. The tasks in the GEL resources were custom designed for each exhibit. For instance, some tried to address misconceptions (related to two exhibits in particular), another guided students' attention to key features of a particularly complex exhibit, and others used concept cartoons (cartoons presenting science in everyday situations [Keogh & Naylor, 1999]) to facilitate content-related group discussions. In addition, the D-GEL design utilized the possibilities interactive multi-media tablets provide for students to take pictures, and for formative assessment (Black & Wiliam, 2009) by representing feedback and scores based on students' responses to various questions. Moderate gamification (Deterding, Dixon, Khaled, & Nacke, 2011) was also employed with the aim of presenting the scores in an engaging manner. The digital tablets presented the tasks using a set of windows, and the other three designs presented each task on one side of a sheet of paper. Finally, consistent with our conceptual framework’s emphasis on group work, the GEL designs aimed to encourage cooperation and discussion, in particular by stressing the need for group organizers to solicit input from all students in the group. The Appendix has examples of the designs (Figures A1- A4) and a summary of the features of each design type (Table A1).

Participants

Invitations to participate in the study were sent to schools in the region of the science center. The fourteen participating classes came from twelve state schools situated in different boroughs in a small city in Norway. There were eight classes of year 6 students (ages 11-12) and six year 7 classes (ages 12-13), with a total of 364 students. Approximately half of the students were female and all were from similar middle or lower middle social class backgrounds. (The social class structure in Norway is relatively flat.) Nearly all were White and all spoke fluent Norwegian. All of the classes (and, consequently, nearly all of the participating students) had visited the science center previously.

Video recordings from each class were used as data. Of the 14 participating classes, three used Open Exploration materials, three used the Traditional Worksheet design, four were given P-GEL materials, and four were given D-GEL materials.

Data Collection and Analyses

Each visiting class was divided into five groups by their teacher. Two students in two of the groups from each of the 14 classes were equipped with head- or chest-mounted video cameras. That is, 28 groups altogether were recorded. The groups, including the students within the groups wearing cameras, were randomly selected. The use of two cameras for each group made it possible to capture the behavior of all students who were engaged in the group's activity. The video recordings from the group in each class that most clearly showed the activities of all students in the group were used for the analyses. The 14 groups whose behavior was recorded included 64 students,[2] 37 girls and 27 boys. All spoke fluent Norwegian; four were non-White. Due to population homogeneity in this part of Norway, analysis by social class or ethnicity is not feasible. Moreover, exploring demographic variation would have required a considerably bigger and more diverse sample and, as such, was beyond the scope of the current research.

Video recordings of students working with the four different designs were analyzed to identify the presence or absence and frequency of pre-defined behaviors. Behaviors fell into two broad categories: (a) those consistent with overall engagement in the learning environment and (b) those comprising Multi-Modal Discussions (i.e., indicative of deeper learning). These behaviors are defined in Tables 2 and 3, respectively.

Table 2

Behaviors associated with overall engagement in the learning environment

Category	Category description (and associated behaviors)
Observation of phenomena	Observation of focal phenomena presented by exhibits Direct interaction with exhibits Observation of other students' interactions with exhibits
Interaction with text	Interaction with text containing terminology related to the focal concepts Reading text on handouts or labels Listening to other students reading handouts or labels
Cooperation	Cooperation during task completion: this is an overall characterization of group organization, student participation, and mood

Discrete observable verbal and non-verbal behaviors were chosen as units of analysis to facilitate accurate coding of specific behaviors (Tables 2 and 3). Instances of behaviors might differ in duration; for instance, a long or short comment on function would each be counted as a single occurrence. As students' wordiness and ways of expressing themselves differ, we believed further specification during the analysis would not necessarily lead to more precise identification of behaviors associated with overall engagement (with texts and phenomenon) or indicative of MMD.

Table 3

Behaviors constitutive of Multi-Modal Discussions

Category	Description (and associated behaviors)
Expressing understanding	Expressing understanding of the target exhibits
	Talk, commenting on function
	Talk, commenting on scientific content
	Instructing others, exhibit operation
	Instructing others, observation of phenomena
	Bodily expression, pointing at phenomena
	Bodily expression, other gestures
Feedback on others' thinking	Feedback on thinking expressed by other students
	Commenting on other students' talk or actions
	Actions in response to others' actions
Inviting others	Inviting others to present their understanding
	Asking questions related to exhibits
	Asking questions related to task
Testing individually	Testing understanding, or relating to previous experiences
	Testing an idea by handling exhibit
	Repeated handling of exhibit
	Comments related to pre-visit experiences
	Comments related to experiences from earlier in the visit
Testing socially	Testing understanding by expressing it to others
	Suggestion related to tasks
	Expressive thinking related to tasks

Written descriptions of how students cooperated during task completion and teacher involvement were created based on the video recordings. The coding framework with specific behavior codes, presented in Tables 2 and 3, were applied for each of the five exhibit-related tasks (involving the five focal exhibits). To log behaviors recorded by video we used the European Exhibition Evaluation Tool[3] (EEET) technology with a configuration that was customized for our purposes. The EEET hardware consists of one computer with two screens. One screen runs two video recordings synchronously. The other is a touchscreen which presented the behavior names with virtual buttons. Events are coded by manually pressing a behavior-code button on the touch screen when the corresponding behavior is observed on the videos. Pressing of behavior-code buttons is recorded by the software. Behavior logging was conducted across individuals within the groups (i.e., observed behaviors of all students in each of the target groups were recorded). The log is presented as an Excel file in which each row contains the name of the specific behavior-code, student identity tag, and a time stamp.

To check for inter-coder reliability, two of the 14 video recordings were also coded by a colleague not involved in this study. This process involved assigning codes from the coding manual to incidents of student activity identified by a student identity tag and the time stamp generated by the EEET software. Inter-coder reliability was found to be 0.723 (Cohen's kappa), with disagreements resolved by discussion.

Results

This study focuses on how designs of self-guided material may be related to students' learning-related behaviors. Our unit of analysis is at group level, due to the importance of interactions (including observations of others) in our conceptual framework. Although some behaviors (e.g., reading a text) can be considered to occur at the individual level, these are aggregated across students in a group. Video data were analyzed quantitatively to compare differences in frequencies of observed behaviors across the four design types. This analysis responds to our research question by investigating differences in overall engagement with exhibits and text (using the codes presented in Table 3) and in MMD behaviors, which are indicative of deeper engagement and ongoing learning (employing the coding schema from Table 4). Additionally, we utilized field notes to characterize group organization and interaction (e.g., cooperation) qualitatively, as a way of enriching and situating the findings and providing a broader perspective on behavioral differences that were observed as students used the four design types.

Overall Engagement with Exhibits and Scientific Texts

Two aims of the handout designs were to facilitate student cooperation and sharing of their experiences and to promote a high degree of involvement with the elements of the learning environment. To examine the way in which the resources may have shaped interactions with two of these elements, namely the exhibits and the corresponding text (in the handouts and in the exhibit labels), we utilized the EEET software to register students' engagement. Figure 1 presents student engagement with exhibits (corresponding to "Observation of phenomena" in Table 2) and text ("Interaction with text") for each of the four design types. The columns for exhibit engagement in Figure 1 are based on combined counts of students' direct interactions with target exhibits and focused observations of others' interactions with those exhibits. More specifically, at each exhibit, whether or not a student engaged with the exhibit (directly or via observation) was noted and then summed across exhibits. Likewise, the columns for text engagement reflect combined counts of reading and listening to others read exhibit-related texts containing focal concepts. Although there was some degree of variation among groups within design type, these were minor compared with differences across design types. Consequently, and for clarity, Figure 1 combines data across groups using each design.

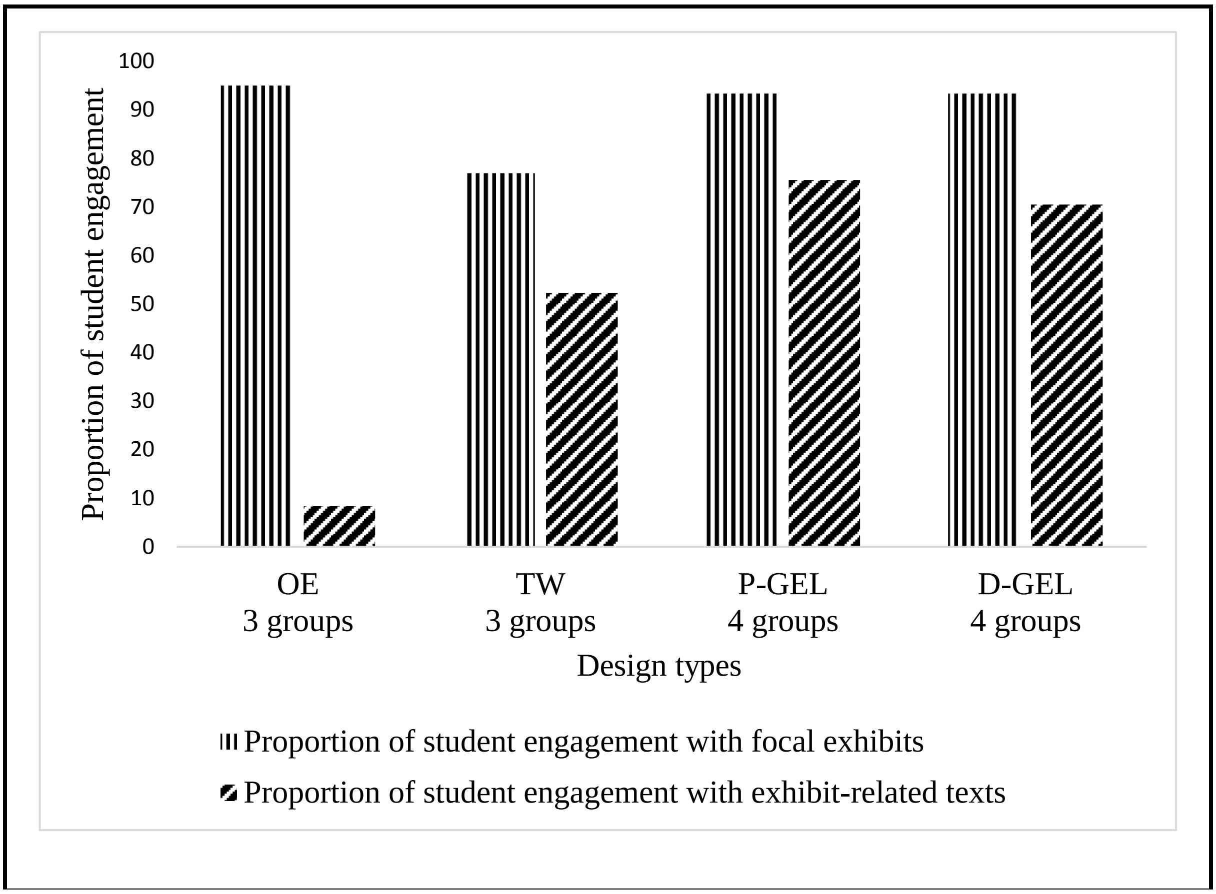

*Figure 1***.** Students' overall engagement with the learning environment (exhibits and text) for the four designs: Open Exploration (OE), Traditional Worksheet (TW), Guided Exploratory Learning – Paper (P-GEL), and Guided Exploratory Learning – Digital (D-GEL).

In the case of unguided Open Exploration, nearly all students either used the focal exhibits directly or observed others using them. That is, in this design condition, there were 60 possible student-exhibit engagements (12 students, across 5 exhibits). As 57 engagements occurred, Figure 1 reflects 95% student engagement. However, labels were read by only a few students in one of the groups. In contrast, fewer students seem to be engaged with exhibits when the groups were assigned to work with the Traditional Worksheets compared with the open exploration case; however, the worksheets resulted in more students reading or hearing the names of the focal phenomena from the associated texts. Handouts based on GEL design principles generally resulted in the highest degree of engagement with elements of the learning environment (both exhibits and, especially, texts) compared with the OE design and the TW design. Students experiencing D-GEL design did not display higher overall engagement than those in the P-GEL groups. Chi-square analyses were carried out to investigate whether the differences in observed engagement (with exhibits and with text) among the different designs were statistically significant. There was a significant association between the type of design (GEL versus non-GEL) and whether or not students engaged with text or exhibits, $\chi^2(3) = 57.6$, $p < 0.001$. There was no significant association between type of GEL design (P-GEL versus D-GEL) and whether or not students were engaged, $\chi^2(3) = 1.6$, $p = 0.667$.

Characteristics of work within groups. In addition to the analyses above, we examined the way students interacted in their groups to further characterize their overall engagement in the learning environment. In particular, we focused on group organization, students' participation in their group's work (i.e., active or passive), and the overall mood or emotion observed within the groups. Data in this section come from observations recorded via field notes.

Students in groups given the Open Exploration handouts tended to stay in their groups throughout the visit. There appeared to be no need for anyone to keep the group together; however, one student in each group adopted an authoritative role, which was manifested in different ways. For example, in one group, a student took the lead in telling group members what she thought about the content of the exhibits and instructed the others in their operation. In another, one student read some of the labels aloud for the others or explained the exhibit. In each group, there was typically a majority core of students who were actively involved while the others were more passive observers.

The exhibit content in the Traditional Worksheets guided the action of the groups, but the way in which individual students acted within each group varied. None of the students took responsibility as organizers of their group as a whole, and only a few members in some of the groups worked together during task completion. For two groups, those who were not writing were typically doing other non-task-related activities and were often away from the focal exhibit. The other group stayed together the entire time, but one of the students in that group acted primarily as an observer. In all three groups using this design, the tasks were mainly solved by one student who transcribed the label text. Those who did not take an active role in completing the tasks were not invited by others to do so.

All groups given the P-GEL handouts had at least one person who took responsibility as the organizer for task completion and student activity, although the details of how they did so and the responses and behavior of other group members varied. Although most students were involved, there were a few cases in which others were directly instructed by the organizer to express their thinking when this was requested by the task. Other group members were called back when they went to explore other exhibits.

Finally, in the groups provided with the D-GEL design, one or a few students led the groups and took responsibility as the organizers of task completion. These organizers all tried to include the other students, but did so in varying ways (e.g., by being strict or politely requesting participation). Generally, the groups stayed together in this condition, although one group had two students who worked as a pair and explored the exhibits on the periphery of those who worked directly with the tasks. Two of the groups occasionally read exhibit labels to seek guidance in task completion. Another group started by doing only the first task at each exhibit and then jumping to the final activities before they returned to the remaining tasks. The students seemed eager to explore and interact with the software presenting the tasks and expressed positive emotions (e.g., smiling or dancing) when they received feedback. The positive emotions expressed while interacting with D-GEL were not expressed while working with the other designs.

Although the limited sample size cautions against generalization, two interesting patterns related to group interaction seemed to emerge. First, in nearly all cases, the groups stayed together during the task completion in the exhibition, regardless of design. Second, the students who were acting as (self-appointed) group organizers in the groups given materials with the GEL design (P-GEL and D-GEL) visibly strived to include all group members. This behavior, not seen in the groups using the other two designs (OE and TW), would seem to be in response to the encouragement the GEL materials provided to include all students. Moreover, these attempts to include other group members directly also appeared to have a key influence on group dynamics and the students' involvement in task completion.

Verbal and Non-Verbal Behaviors Contributing to MMD

After looking at overall engagement, analyses of video data (using the EEET software) sharpened to investigate indications of students' deeper engagement. More specifically, the handout designs (especially the two GEL designs) aimed to encourage multimodal discussion (MMD) and, indeed, behaviors indicative of MMD were observed. Figure 2 presents the total frequency of each category of MMD behavior (Expressing understanding, Feedback on others' thinking, etc.; see Table 3) by design type, averaged across the groups using each design. Put differently, the frequencies presented reflect the average of the groups' collective occurrences of MMD behaviors for each design.[4]

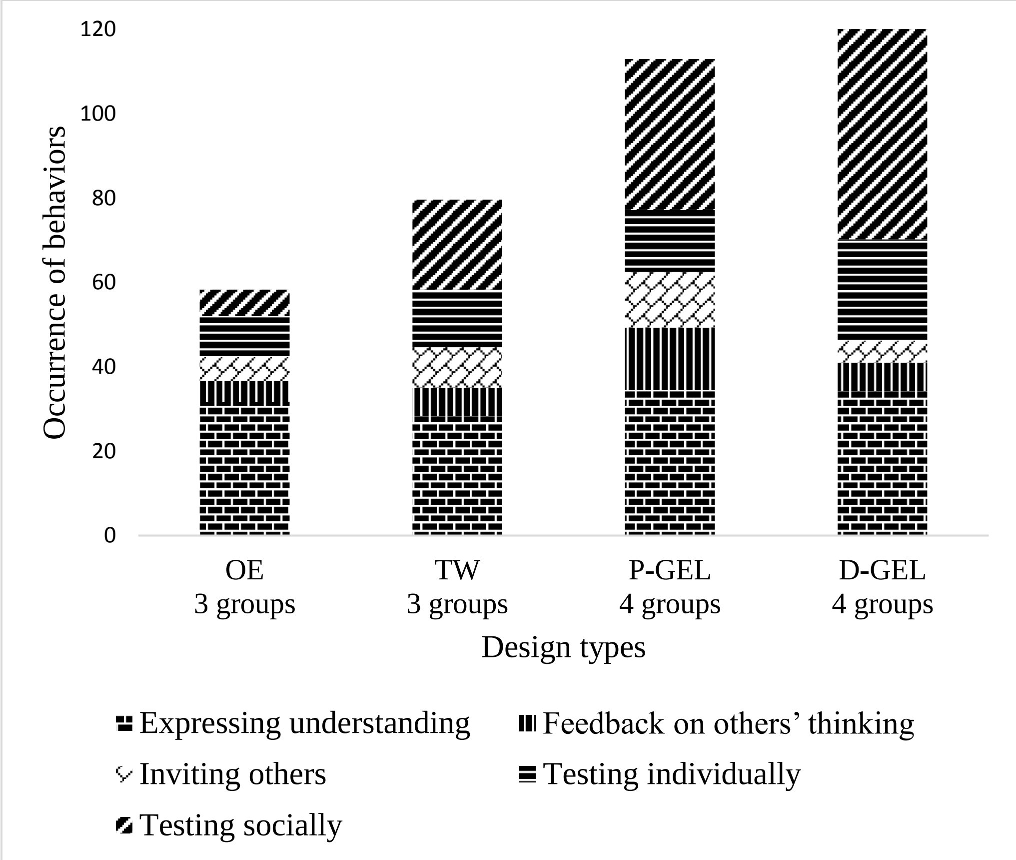

Figure 2. Average occurrence of student behaviors comprising MMD for each design type: Open Exploration (OE), Traditional Worksheet (TW), Guided Exploratory Learning – Paper (P-GEL), and Guided Exploratory Learning – Digital (D-GEL).

As noted previously, a main purpose of this study was to investigate whether a design based on GEL principles had the potential to support MMDs to a greater extent than would less sophisticated designs. To explore this, we treated the MMD frequencies as scores and compared the scores for the eight GEL groups (P-GEL and D-GEL) with those for the six non-GEL groups (OE and TE). A two-tailed test (independent samples) revealed that students in groups using the GEL designs displayed more MMD behaviors (M = 121.13, SD = 37.7), than those in groups using the OE or TW designs (M = 69.0, SD = 20.0). This difference was significant, $t(12) = -3.059$, $p < .01$. A two-tailed t-test comparing the two GEL designs did not demonstrate significant differences in MMD scores between them.

Looking in more detail at the behaviors of groups given the four designs, Expressing understanding appeared relatively frequently in all, regardless of design. In contrast, the frequency of behaviors in the category Testing socially differed among the four designs, being lowest in groups using the OE design and generally highest for both GEL designs. The frequency of the behaviors in the Inviting others category presents a less distinct picture; however, there are generally fewer behaviors of this specific category for the D-GEL than in the P-GEL group. Finally, frequency of behaviors in the category Feedback on others' thinking indicates a similar pattern, having lower values for D-GEL than P-GEL.

Space limitations prohibit full presentation of all sub-behaviors associated with the MMD categories. However, we find it appropriate to mention the somewhat surprising finding that almost no instances of the category Linking to everyday life were recorded in any of the groups even though supporting such linking was one of the design aims.

Discussion

In addressing the research question, we focused on student behaviors that were observed as groups used four different handout designs. Below, we summarize our findings and use these observations to make inferences about the educational quality of the experience. We then consider our findings in light of the perspectives and concepts that underpinned the various designs, namely, joint shared exploration, PFL, practical work, and MMD.

Designs of Educational Materials and Student Behaviors

Elements of MMDs were observed in all groups (regardless of handout design), albeit to varying degrees and quality. However, there were differences among the designs in terms of the overall degree of engagement of group members and how the groups organized themselves in completing the tasks. For example, students using the OE design moved together in groups, and nearly all interacted with the target exhibits; however, only a few students engaged with text by reading or listening. The TW design seemed almost to dissolve the groups (with most students working in pairs or individually), and only a few students were actually involved in completing the tasks. Most students used the exhibits, but only around half of them engaged with the text, and the worksheet questions were mainly answered by copying text directly from the exhibit labels. In contrast, both types of GEL design seemed to support students organizing themselves to work together (as a group) to compete the tasks. Higher proportions of students in these groups also used the target exhibits and engaged with text, compared with students in the OE or TW groups. The group organizers aimed to include their fellow students in the tasks of exploring and evaluating propositions. Working with D-GEL also seemed to lead to the expression of positive emotions, which was not detected among groups using the other designs.

Looking in more detail at the behaviors comprising the MMDs also provides insight into the differences observed between students in the D-GEL and P-GEL groups. In particular, more behaviors in the Testing socially category were observed in the D-GEL group; however, students in this group also exhibited fewer behaviors in the Feedback on others' thinking and Inviting others categories. These differences in the frequencies of behaviors appear to correspond to differences in the organization of group work (described above). That is, differences in the organization of group work indicate that D-GEL, with its tablet-based presentation of the tasks, may have made it more challenging for the self-appointed group organizers to include other students in task completion.

Our limited sample size calls for caution in generalization; however, our results are consistent with some previous studies. For instance, similar to Bamberger and Tal (2007), we found that open structures were related to superficial use of exhibits and few instances of reading. What we termed "traditional worksheets" resulted in limited involvement, as found in previous research (Griffin & Symington, 2007; Rix & McSorley, 1999). Finally, also parallel to other work (e.g., Mortensen & Smart, 2007), our findings suggest that material that aims to guide students' exploration (as with GEL designs) can support behaviors that indicate engagement in the learning environment and associated tasks. Taken together, these findings indicate that materials designed to guide students' exploration have the potential to shape behavior in a way that enhances the quality of the educational experience. However, in contrast to some previous work (Hsi, 2003; Yatani et al., 2004), our findings around the use of digital technology are less clear and indicate that it does not necessarily improve the quality of student experience.

In sum, findings of this study indicate that the design of educational materials may have the capacity to influence students' behavior and that well-designed resources may support desirable learning-related behaviors. Of course, a range of other factors could also have influenced our findings, such as student interest or knowledge, previous experience with science center exhibits, and relationships among group members, to name a few, and our sample size prohibits a thorough exploration of these possibilities. Nevertheless, we find it interesting that resources designed for Guided Exploratory Learning experiences corresponded to a higher frequency of learning-related behaviors and better cooperation within groups than did Open Exploration and Traditional Worksheets materials, and we argue that they seem to generate the highest quality educational experiences. Consequently, the following discussion of quality focuses on GEL-type resources.

Educational Experiences Facilitated by Guided Exploratory Learning

GEL-type resources were designed to elicit and support verbal and non-verbal behaviors that are elements of Multi-Modal Discussions (Hauan et al., 2015) and are indicators of deep engagement. Analyses of observational data highlight that students in groups using GEL designs were, indeed, involved in joint activity, and, moreover, indicate that this work supported MMD. In sum, the findings strongly suggest that the students were deeply engaged with the learning environment.

A key idea underpinning GEL design is to make use of (hands-on) exhibits, educational materials (handouts and labels with text articulating focal concepts), students' prior experiences, and the group members themselves as learning resources and to incorporate these resources into a holistic learning environment. Such designs aim to create a learning experience that is shared among group members, although individual students' contribution to given tasks will vary for idiosyncratic, social, or practical reasons. Nevertheless, in accordance with Wells (1999), we argue that all students who are involved in such a holistic learning environment will learn from the experience 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" (Wells, 1999, p. 219). The findings presented in this paper reflect the way in which both GEL designs, particularly the P-GEL, encouraged students to stay together and explore as a group. This joint shared exploration was seemingly facilitated by the design itself, which provided the self-appointed organizer(s) with a mandate to get every group member's opinion on the questions. Moreover, we suggest that all students who were involved in the joint shared exploration were likely to have been fruitfully prepared for future encounters with focal scientific concepts.

In summary, this study suggests that GEL design has the potential to result in joint shared exploration within a holistic learning environment in which all participants had an experience that supported them in their individual progress toward understanding focal concepts. Findings related to MMD also suggest that GEL designs supported students' linking between the objects they encountered, the scientific ideas presented by the text, and the underpinning phenomena, thus supporting their learning of scientific concepts.

Suggestions for Further Research

The findings suggest two possible areas that may prove fruitful for further research: (a) how to exploit most effectively the potential of digital resources for guiding students' exploration and (b) how to facilitate links to students' prior knowledge.

Prior studies indicate that digital technology may have a positive influence on conceptual learning outcomes (Hwang et al., 2012; Kahr-Højland, 2010; Yatani et al., 2004). However, the D-GEL design, with its tablet-based task presentation, seemed to make it more challenging for the self-appointed group organizers to include other group members in the tasks. Nevertheless and in line with previous research (Hsi, 2003; Kahr-Højland, 2011; Yatani et al., 2004), this study indicates that students' enjoyment is enhanced by the use of technology and moderate gamification. Additionally, we argue that positive emotions should be a focus of both design and evaluation because enjoyment is linked to engagement, which is considered to enhance learning (Ausubel et al., 1978; Dewey, 1997). Thus, based on prior studies and observations of students' enjoyment of D-GEL experiences, we would consider design guidelines that exploit the potential of digital resources for guiding students' exploration to be an interesting area for further research, especially with respect to supporting group organizers.

Turning to the second area for potential future research, illustrations that presented the way focal concepts are encountered in everyday life were included in the designs to support students' linking them to their existing cognitive structures (Ausubel, 2000). Although it does not seem unreasonable that these illustrations were noticed by students, we did not capture any evidence of students' actual use of them. Consequently, we lack evidence related to one of the four principal elements of the GEL design. One possible solution would be to present illustrated orienting questions, designed to activate concept-relevant knowledge related to everyday life. Such questions were found to have the potential to enhance students' learning outcomes from science lessons (Osman & Hannafin, 1994). By including illustration-related orienting questions, we may be able to both obtain information on students' use of the illustrations and potentially support linking, thus enhancing the quality of the educational experience.

Conclusion

We acknowledge that the limited number of groups involved in testing each design type necessarily limits the generalization of our findings. However, when considered in the context of previous studies, this research contributes to the field's understanding of the way in which particular designs of materials can support learning. Our results indicate that handouts designed to scaffold students' exploration of interactive science center exhibitions in particular ways (i.e., by directly encouraging group interactions) could potentially support students' learning. More specifically, our findings suggest that materials that were designed to facilitate a guided exploratory learning experience helped establish a learning environment in which the available educational resources (exhibits and texts) and participating students formed a holistic learning environment that could support deep engagement in the environment and encourage multi-modal discussions. Our findings suggest that these GEL designs seemed to facilitate students' forming links between objects (or exhibits), science concepts presented in associated texts, and underlying focal phenomena, thus supporting their progress towards conceptual understanding (Millar, 2004; Tiberghien, 2000). Therefore, we encourage science center practitioners to consider such features of GEL design when developing materials for school visits.

The framework applied in this study to gauge the quality of educational experiences in a science center is a further development of the evaluation framework presented by Hauan et al. (2015). The framework involves evaluating learning resources (handouts) by carefully attending to overall engagement with the learning environment, characteristics of work within groups, and the presence or absence of elements of multi-modal discussions. The principle of using observed behaviors to evaluate material for self-guided experiences in exhibitions has parallels with principles applied by Barriault and Pearson (2010) to evaluate single exhibits. We argue that the framework presented in this paper has the potential to support research in the field, continuing to develop and build on previous efforts such as the Visitor Engagement Framework (Barriault & Pearson, 2010). We hope that the methods and results presented in this study provide inspiration for the innovative use of exhibitions as learning material for schools and for further evaluation and research around such experiences.

Notes

1. Primary school in Norway covers grades 1–7, ages 6–13.
2. Number of students per class varied from 17 to 30. Each class was divided into 5 groups (corresponding to the number of focal exhibits). This resulted in 3-6 students per group.
3. The European Exhibition Evaluation Tool (EEET) is a software tool developed by a consortium of five major European science centers and one exhibit supplier. The EEET project aims to develop a set of tools that can evaluate several important aspects of visitor behavior in science centers in a consistent and time-efficient way (www.eeet.eu).
4. The MMD frequencies are likely to be related to the length of time groups spent in the exhibition. However, prolonged engagement, and thus more discussion and exhibit handling, was a goal of the handout designs. Moreover, all groups spent comparable lengths of time in the exhibition (between 53 and 68 minutes, with some of the variation due to waiting time). In addition, although it would be interesting to explore inter-group differences based on demographic characteristics (e.g., ethnicity, social class) our sample is both too homogenous and too small to make valid comparisons.

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Appendix

Table A1

Characteristics of the four handout designs

Characteristics of educational materials	Open Exploration (OE)	Traditional Worksheet (TW)	Paper-presented Guided Exploratory Learning (P-GEL)	Digitally-presented Guided Exploratory Learning (D-GEL)
Hardware	paper	paper	paper	multi-media tablet
Aims to focus student observation toward particular phenomena (related to focal concepts)?	no	no	yes	yes
Aims to direct students' handling of exhibits?	no	yes	yes	yes
Directly encourages discussions within groups?	no	no	yes	yes
Uses illustrations to try to link concepts to everyday life?	no	no	yes	yes

Available text with names of focal concepts?	on exhibit labels	on handouts and on exhibit labels		
Design approach for exhibit tasks?	not applicable	same design type for all exhibits	custom designed based on exhibit characteristics	
Open / closed tasks	open	closed	closed	closed & open
Formative assessment?	no	no	no	yes
Gamification?	no	no	no	moderate

Note. Students in each class were provided with one of the four types (or designs) of materials.

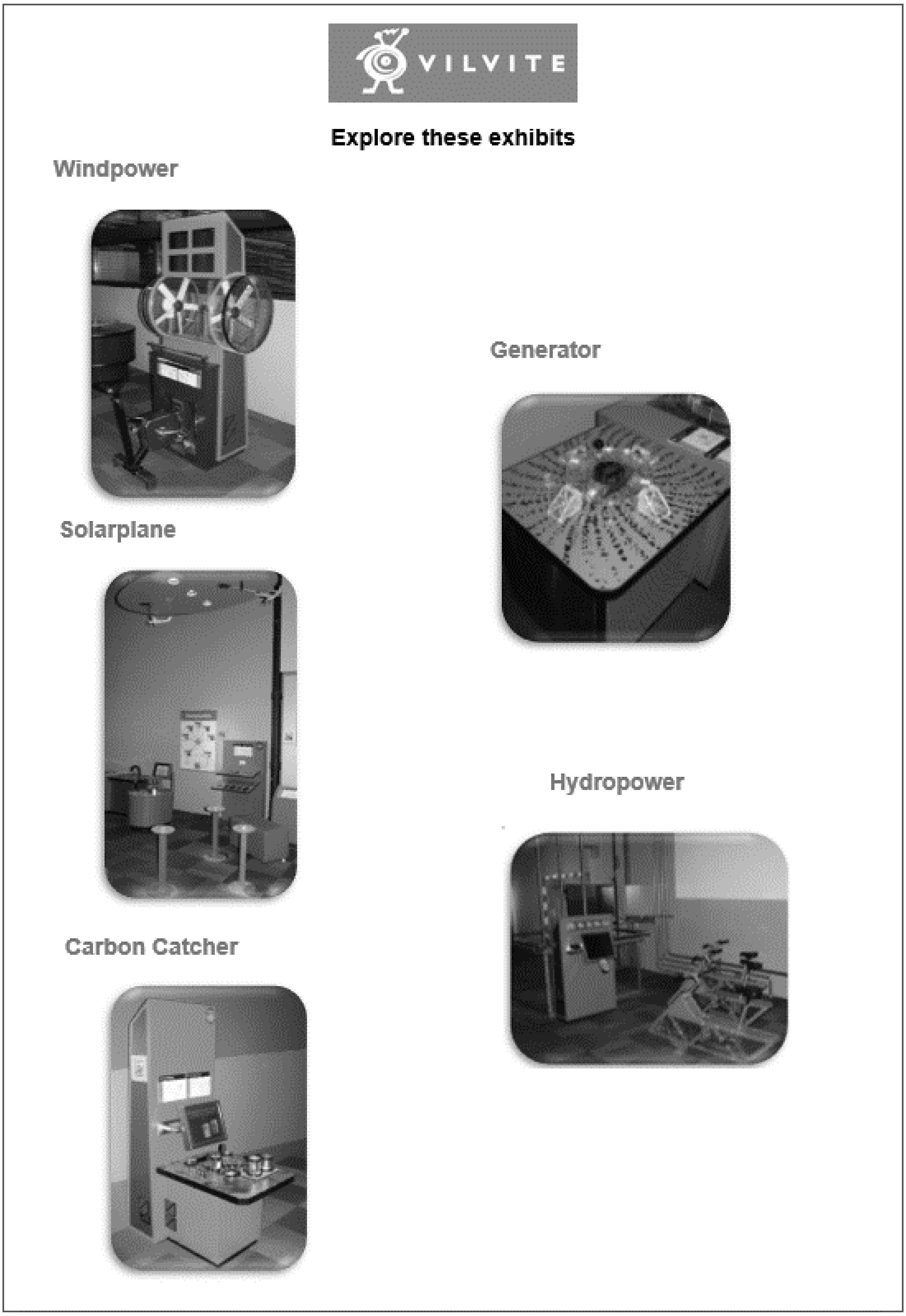

Figure A1. Open Exploration sheet for all of the exhibit-related tasks (text translated from Norwegian)

VILVITE

Energy from Wind

Go to the exhibit Windpower

1. Generate wind
2. How does the windmill get kinetic energy and start turning?

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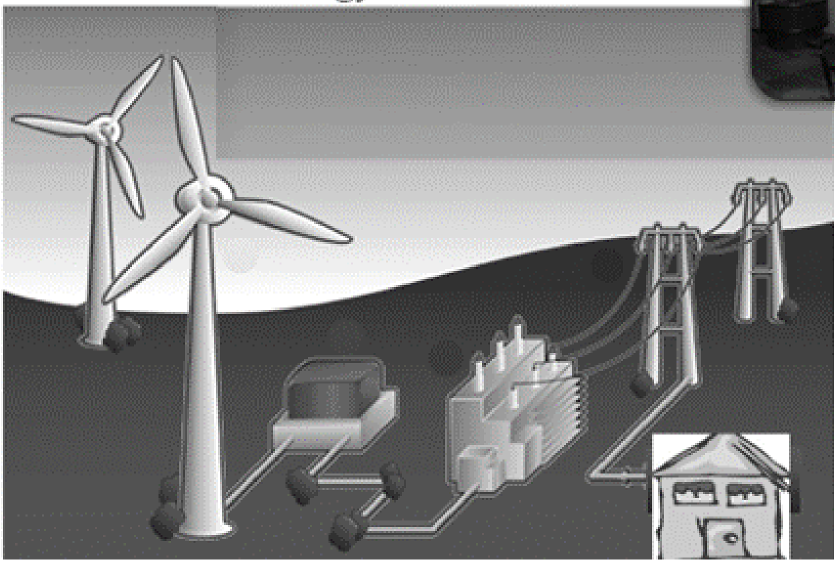
3. Why are windmills useful?

Figure A2. Traditional worksheet sheet for one of the exhibit-related tasks (text translated from Norwegian).

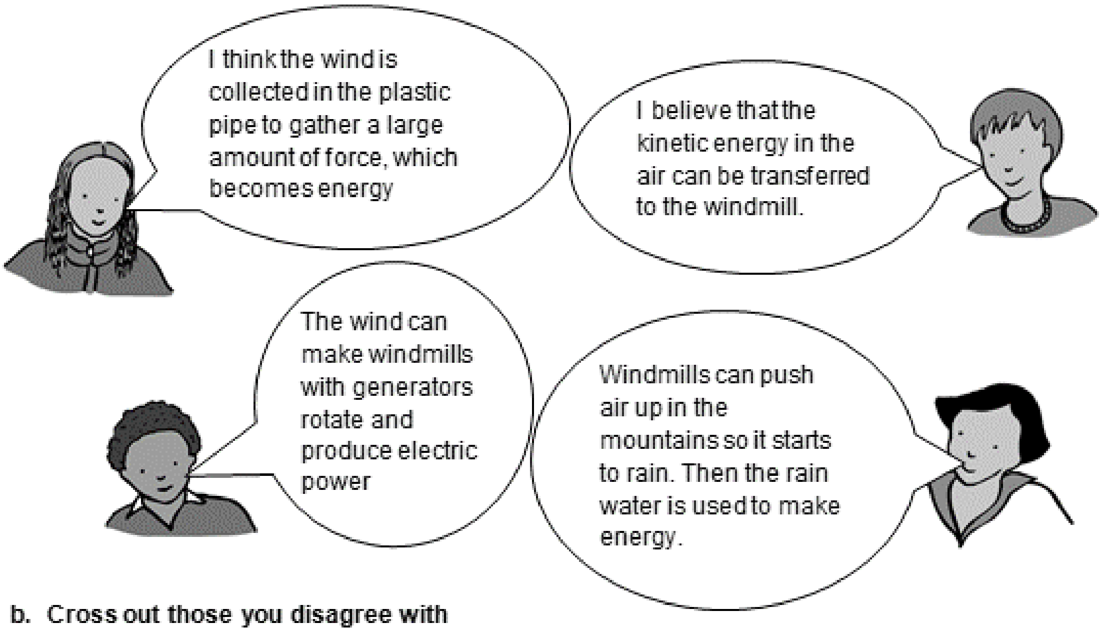
Energy from wind



task 1.
Use the pedals to activate the fan to make the windmill rotate
Pedal quickly so the light bulbs in the black rooms on the top are lit

task 2.
Below is a drawing of four students who discuss the question
How can we make electricity with wind?

a. You must agree and circle those you most agree with.



b. Cross out those you disagree with

Figure A3. Paper-based GEL sheet for one of the exhibit-related tasks (text translated from Norwegian)

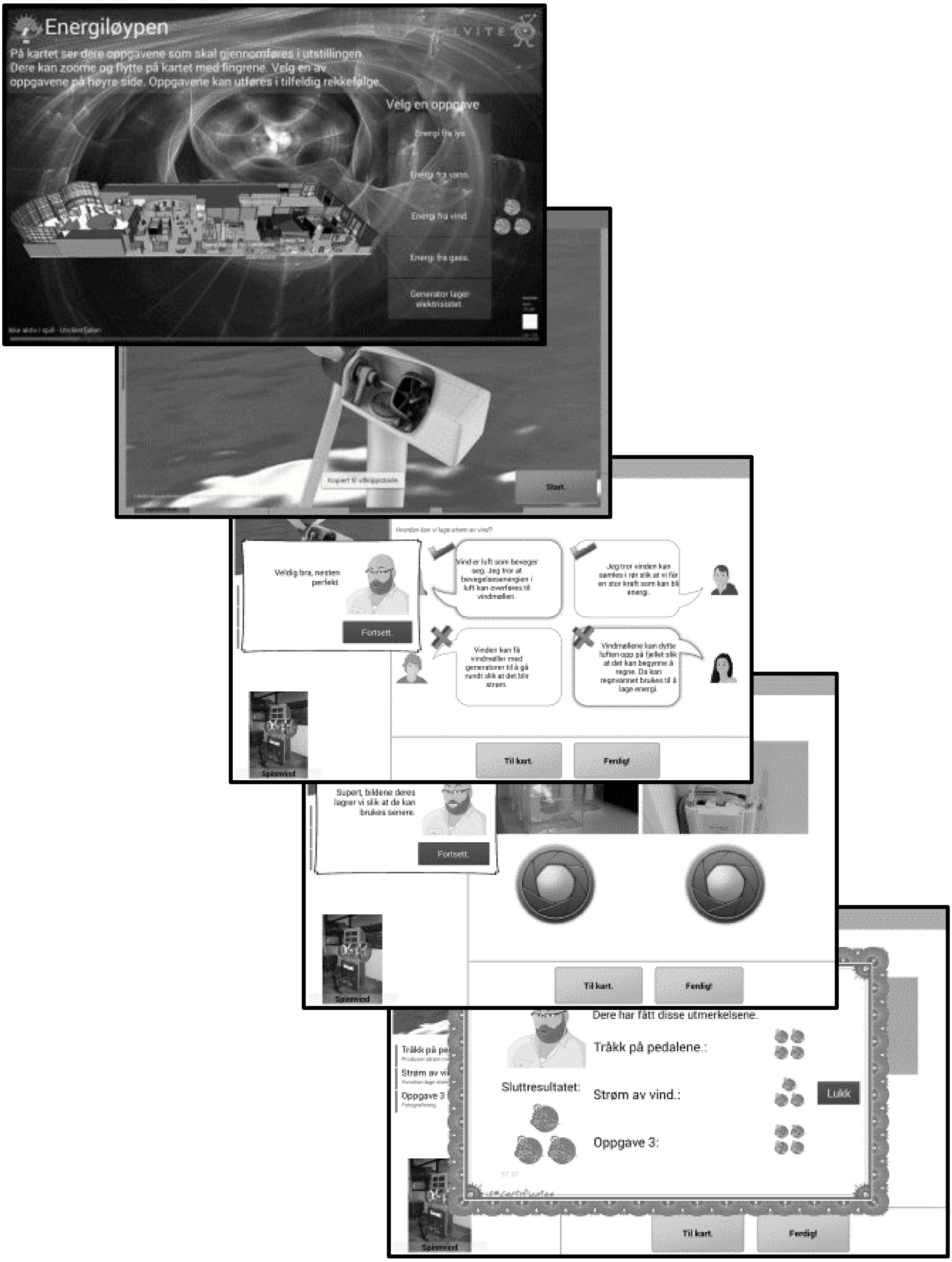


Figure A4. Digitally presented GEL windows for one of the exhibit-related tasks from the map to the final formative assessment window (text in Norwegian)