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Peers, teachers and guides: a study of three conditions for scaffolding conceptual learning in science centers

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Abstract

Studies of education practices in science centers have found variation in how conceptual learning is supported, or scaffolded, on school field trips. This paper investigates the implications of scaffolding variations for how students make sense of a game-based exhibit that was designed to trigger interest and develop knowledge of scientific phenomena. The data were gathered during a field trip by high school students (aged 16–17 years) to a science center. The activity was part of a larger design-based research project, and this study focuses on students' encounters with a single exhibit while in small groups. The group arrangements are characteristic of how learning activities are organized on field trips and represent three common *conditions for scaffolding*: (1) peer-supported, (2) teacher-assisted, or (3) facilitated by a museum guide. Interactions in each condition were video-recorded, transcribed, and subsequently scrutinized using interaction analysis. The analysis shows how framing, dialogic approaches, and the game-based exhibit facilitated sense making within and across the different conditions. The paper considers the scaffolding intentions and means of each condition and discusses the consequences of the variations for the students' conceptual learning. The complexity of science center exhibits is also considered, as the study identifies scaffolding challenges related to interactions with dense and comprehensive analogue and digital resources.

Keywords Conceptual learning · Framing · Scaffolding · Science center · Field trip

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Science center educators are charged with developing learning activities and materials for teachers' and students' use on school field trips, with the overall aim of engaging students in science curriculum in new and exciting ways. However, studies show that the most significant learning effects from science center visits are linked not to the actual field trip, but to planned activities in the classroom before and after a visit, when teachers manage to relate the onsite experience to disciplinary content and concepts in the science curriculum in school (DeWitt and Hohenstein 2010). In practice, this is a problem, in that integrating learning activities in school with science center experiences has proven difficult for teachers, who tend to prioritize the use of classroom lessons to cover specific topics in the curriculum as activities 'apart from' rather than 'linked to' field trips (Kisiel 2005). While improved inter-institutional collaboration is clearly important in addressing this gap, the dilemma also reinforces the view that the unique opportunities for learning in the actual science center environment should be maximized. In a school field trip context, this entails pedagogical designs that employ a range of approaches to facilitate, or scaffold, inquiry and students' conceptual development onsite.

There is no consensus on how to best scaffold learning in science centers. On the one hand, there are concerns in research and in practice that guided assistance and a focus on directed learning may diminish the science center's distinctive attraction as an alternative and engaging informal educational arena (Anderson, Kisiel, and Storksdieck 2006). On the other hand, there is acknowledgement that certain types of facilitation have been shown to support more in-depth learning. Numerous studies in the learning sciences confirm the value of appropriate facilitation for inquiry-based and conceptual learning (Sawyer 2006). Accordingly, one large aim of learning research in museums is to study how facilitation may best be accomplished for different types of visitor groups (Gutwill and Allen 2012). In sum, the use of facilitation in science centers varies broadly and is often non-existent (Yoon, Elinich, Wang, Van, and Schooneveld 2013). It is this 'gap' in practice that serves as the background for this study.

As part of a larger project that applied design-based interventions as a method (see Jahreie and Krange 2011), this study explores students' efforts to make sense of a game-based interactive heat pump exhibit during a field trip to a science center. Energy transfer was the conceptual learning focus of the designed exhibit, and the students were organized into group arrangements that represent three common *conditions for scaffolding*: peer-supported, teacher-assisted, and guide-facilitated. We recognize that students' uptake during scaffolding is known to vary (Bakkene 2017); the quality of scaffolding depends not only on the facilitator but on the participating students and how they interact to accomplish a task (Mascolo 2005). Therefore, this small and targeted study does not aim to propose exclusive categories or to generalize based on our findings. Instead, we contribute insight into variations across three common facilitation conditions on school field trips, providing a basis for further discussion of how conceptual learning—and learning the curriculum in new and exciting ways—may best be supported.

The article is structured as follows. Beginning from our research questions, we outline our theoretical framework, which is based on a sociocultural and dialogic perspective on sense making and conceptual learning, before going on to describe the design-based research setting (Brown 1992). The participants were a teacher, a museum guide, and groups of high school students (aged 16–17 years) interacting with an exhibit. After discussing the analytic approach and methodological considerations, we present and analyze three episodes of student interaction (Jordan and Henderson 1995), each representing a different facilitation condition. A discussion of findings follows, where we relate our findings to previous experiences and knowledge. Based on the empirical study, we identify variations within and across the different conditions, and we consider types of on-site facilitation that seem most productive for orientinging students' sense making toward conceptual learning in science centers. Finally, we suggest some directions for future research.

Research questions

The overarching research question asks how different facilitation conditions are accomplished in interactions between students, facilitators, and the exhibit. The study investigated three such conditions. The *peer-supported group* was included because students commonly explore science centers on their own or in small groups (Allen 2002). In analyzing this group, we posed a number of broad questions, including the following. *What types of knowledge issues (if any) were raised, and how were they addressed? How did the students make sense of the resources inscribed in the exhibit?*

Inclusion of the *teacher assisted* group elaborates on studies documenting a lack of clarity about expectations for teacher participation during field trips, about teachers' intentions for field trips, and about the teacher's role during field trips to science centers and other museums. It has frequently been reported that teachers are not primarily focused on contributing to students' inquiry processes, instead viewing their role on field trips as geared more toward supervising, leading, baby-sitting or safety (Burtnyk and Combs 2005). Nor do teachers relate the field trip experience to scientific concepts in the curriculum when back in school (Bamberger and Tal 2007). A larger survey study by James Kisiel (2006) concluded that teachers evaluated a field trip's success primarily on the basis of students' enjoyment and other emotional criteria rather than in terms of curriculum-oriented learning outcomes. Therefore, in this study, the teacher was explicitly assigned a central role in following up on students during their interactions with the exhibit. The following research questions were posed to address this form of facilitation: *In which ways (if any) did the teacher take part in discussions related to conceptual issues? How did the teacher draw on resources inscribed in the exhibit?*

Finally, the *museum guide* condition was included because guides most frequently introduce students to the science center and facilitate group or whole-class discussions that are typically part of such visits. However, there is some evidence that guides' lectures are likely to focus on facts and concepts relative to the phenomenon and often linked to the school curriculum, leaving less time for more open reflection and interaction. There is also evidence that 95% of guides' questions require yes/no answers rather than prompting students to analyze, synthesize, generalize, and evaluate knowledge gained from interacting with exhibits (Tal and Morag 2007). Rather than expecting answers from students, guides pose questions more as rhetorical moves during lectures that are often dominated by jargon and limited explanations (Pierroux 2010). This is significant because such an approach is the opposite of conceptual learning in schools. While guides in science centers tend to provide students with facts, sense making in school is essentially task-oriented, putting students at risk of never really grappling with conceptual issues. The research questions for the group with the guide thus center on the students' sense making when interacting with an exhibit. *In which ways (if any) did the guide relate curriculum and classroom experiences to students' interactions with the exhibit? How did the guide draw on resources inscribed in the exhibit?*

Sense making with exhibits

Framing and intersubjectivity

Sociocultural approaches in the learning sciences explore sense making—how students understand and interact in a learning setting—as a collaborative accomplishment that is always mediated by cultural resources, including talk (Vygotsky 1978). Over the last decades, interest in the mediational role of talk has informed studies of *visitors' conversations* in science centers and museums, investigating sense making as a situated, emergent, relational, and social process. In one of the largest studies of museum learning, Gaea Leinhardt and Karen Knutson (2004) applied a sociocultural approach to the study of groups visiting different types of museums. Learning was measured by analyzing the amount of *conversational elaboration*—the extent to which groups went beyond listing details of exhibitions to synthesizing and explaining the exhibitions in ways that were connected to disciplinary content. This approach has been further developed in an interactional direction, for example, in a study of how high school students framed disciplinary topics in science center settings using a mobile video-based learning app (Bakken and Pierroux 2015) and of visitors' embodied interpretations of paintings in an art museum (Steier 2014). The sociocultural interpretation emphasizes sense making as fundamentally social, based on an ethnomethodological epistemology that views the world as *intersubjective* (Schutz 1967).

In the present context, facilitators and students' interactions create a social reality that is at the same time constrained by preexisting social and cultural structures (Ritzer 1992). By virtue of their identities, motivations, and expertise, each participant brings a different perspective to sense making activities (Cole 1996). Their orientation to an activity is informed by who they are, their previous experiences, and their previous knowledge of the domain (Sawyer 2006). A fundamental question is thus how mutual understanding emerges and gradually leads to learning—or, more specifically, to conceptually oriented learning. It is reasonable to expect that orientation to the activity will vary across groups under different conditions, and this effect is exploited here to investigate the role of scaffolding in students' interactions with the exhibit.

When participating in an activity, people need to be attuned to each other's contributions. According to John Shotter (1992, p. 13), "the ordering of our utterances must be negotiated with the others around us in ways that they find intelligible and legitimate." In this context, Irvine Goffman's (1974) concept of frame is interesting and useful, which has been applied to the bottom-up analysis of various intersubjective processes, including sense making (see for example Lantz Anderson, Linderoth and Säljö 2009). According to Goffman, a frame represents the organizing of experiences into meaningful units. The frame constitutes the answer to the question: "What is going on here?" Put differently, frame refers to "a definition of what is going on in interaction, without which no utterance (or movement or gesture) could be interpreted" (Tannen and Wallat 1987, p. 206). This means that the frame, which is interactionally produced, will provide guidance for students and their facilitators on how to participate (Silseth and Arnseth 2016). In this study, framing allows us to analyze which aspects of the scaffolding conditions contribute to the students' learning when engaging with the heat pump game. Specifically, we focus on how the framing and the groups' verbal and physical interactions with a heat pump game mediate their efforts to understand the conceptual issues underlying the phenomenon of energy transfer.

Dialogic approaches to scaffolding conceptual learning

The metaphor of scaffolding was introduced by David Wood, Jerome Bruner, and Gail Ross (1976) to explain the role of facilitators in joint problem solving. Scaffolding is a large topic in learning science research and is linked to Lev Vygotsky's (1986) *zone of proximal development*, referring to the difference between what a student can and cannot do without support. The underlying objective of scaffolding is to help the student—or group of students—to become independent of assistance, which is gradually 'faded' as responsibility for learning is transferred to the student at some point during a learning trajectory (Van der Pol et al. 2010). A characteristic of scaffolding that is particularly relevant for this study is how support is contingent on a diagnosis of a student's level of performance, allowing facilitation to adapt and respond to different learning conditions. Depending on the conditions, the intentions, and the means of scaffolding, for example, the need for contingent support may not necessarily decrease throughout a learning trajectory (Van der Pol et al. 2010). In science centers, where learning interactions are relatively brief, a recent study of scaffolding (Arnseth and Krange, 2016) found that a facilitator's withdrawal may hinder rather than help the pursuit of conceptual learning. This study contributes to research on different conditions for scaffolding in science centers and studies of how to provide contingent support for conceptual learning.

Introducing the notion of *scientific concepts*, Vygotsky (1986) argued that a concept is not scientific unless considered in relation to, or at least as part of, a larger conceptual system. This is not a trivial consideration, and Bransford et al's (2000) extensive review of how people learn found that a major challenge for the learning sciences is related to conceptual development. Qualitative studies illustrate in detail how students and their teachers struggle to move from procedural to more conceptual orientations as part of their problem solving (Krange and Ludvigsen 2008). While performing tasks may be valuable, this is often insufficient to support conceptual learning; students often have problems making connections and understanding relations between a task and a larger conceptual system. Studies of scaffolding that supports conceptual learning have particularly focused on the *role of talk* and dialogic teaching approaches (Edwards and Mercer 1987). This body of research has shown that dialogic teaching approaches that orient students' sense making toward conceptual learning share some common features, e.g., participants acknowledging each other's contributions and taking them seriously, listening to each other's perspectives, and building on each other's ideas and views. In museum learning studies, findings show that instructors can support this kind of sense making by eliciting students' understandings, inviting them to contribute, rephrasing students' contributions (revoicing), and enabling students to expand on their propositions and contributions (Pierroux 2010). In addition, dialogic approaches that enable students to link scientific concepts to previous experiences and knowledge are emphasized, e.g., approaches that support students in mastering specific types of inquiry discourse in science center settings (Gutwill and Allen 2012), or in using their everyday knowledge or experiences as resources in educational dialogues (Silseth 2018). These dialogic skills serve as potential learning resources when working with science concepts during tasks. Consequently, when analyzing students and facilitators' interactions with the heat pump game we pay particular attention to how features of talk are oriented to scientific concepts, e.g., how concepts are introduced and taken up in the conversations, as well as how different cultural resources are mobilized across different scaffolding conditions.

Research design

Most studies of science centers and museums focus on learning outcomes and the different factors that impact those outcomes (Falk and Storkdieck 2005). In studies that address social interaction, the utterances of museum stakeholders and visitors have generally been coded separately, using extracts of talk to illustrate categories identified in the analysis (see e.g., Allen 2002). This approach is not generally useful for understanding how sense making evolves, unfolds, and becomes directed during interaction, or how exhibit resources are exploited in conversation. The research design for this study is focused on collecting and analyzing moment-to-moment interactional achievements. The data were collected from the third and final iteration of a design-based research project (Brown 1992), which was conducted in partnership with a prominent Nordic science center. Such design-based approaches are widely used in school-based research and are increasingly employed in studies of museum learning (Falk 2004).

In the larger project, the students' activities spanned two institutional settings: a high school and a science center. The participating students used both analogue and digital tools as learning resources, some of which were selected for further development as distributed scaffolds (Puntambekar and Kolodner 2005) to improve and support science-related sense making across the two settings. This research has been documented in publications focused on transfer across learning trajectories (Jornet, Roth, and Krange 2016) and on the students' bodily experiences in science inquiry (Jornet 2015). Efforts to strengthen the coherence of science education across scientific concepts, tasks, and institutional settings were a key component in developing the sense making trajectory, including the game-based interactive exhibit in the present case.

In parallel with this research project, the science center was about to embark on the design and development of a new exhibition on sustainable energy. Project researchers collaborated on the design of this exhibition, contributing knowledge about technology-rich teaching and learning in science, interaction design of the game-based heat pump exhibit, and the programming and commissioning of the exhibit's digital features.

The game-based heat pump exhibit

The exhibit was designed as an interactive gameplay experience involving both digital and analogue resources, and students received a percentage score for their gameplay performance. Through strong links to the relevant conceptual content (Fig. 1), the aim was to strengthen coherence across learning activities at school and in the science center. Before visiting the science center, the students interacted with and interpreted small experiments related to pressure, temperature, boiling point, and energy transfer as conceptual issues that might inform sense-making when interacting with the heat pump exhibit.

The idea of the heat pump is that the inside temperature of a house can remain stable throughout the year, regardless of changes in the outside temperature. One important feature is that air can go both ways, heating cold air (heat pump) and cooling hot air (air conditioning). This embodies the concept of energy transfer, as well as physical laws related to pressure, temperature, and boiling point. The students were exposed to these topics before visiting the science center by performing small scale experiments at school and interpreting what these might illustrate.

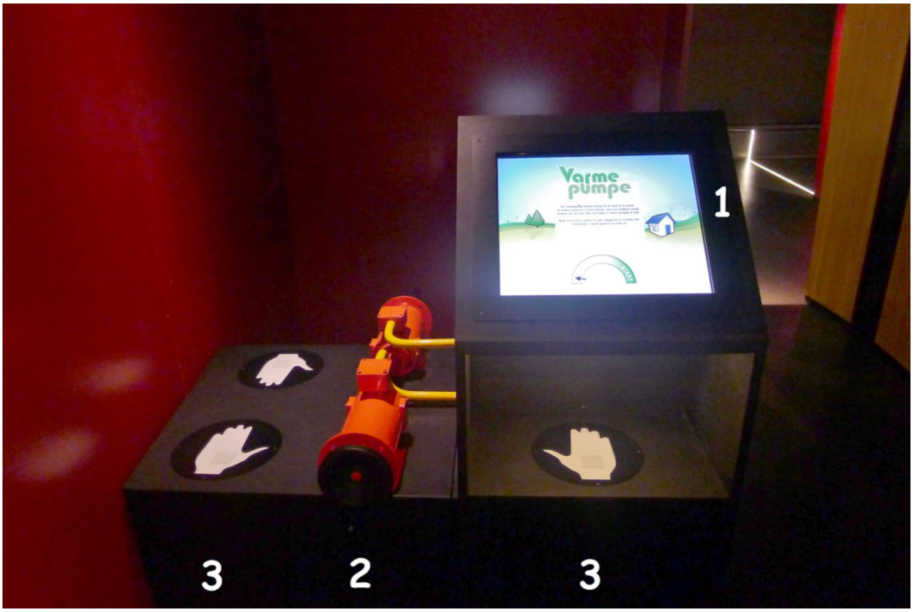

Fig. 1 The exhibit

The analogue tools were (2) a crank and (3) so-called "Pelletier hands." The crank could be turned both ways, and the participant had to use it to increase or decrease the inside temperature. The Pelletier hands emitted warmth according to which way energy flowed; when energy was moved into the house, the hand on the right emitted warmth and the other became cold; conversely, when energy was moved out of the house, the Pelletier hand on the left became warm (Fig. 1). The digital feature (1) consisted of a monitor that displayed information before, during, and after gameplay about the temperatures inside and outside a house during the course of a year (Fig. 2a–d).

In addition, a text describing the function of a heat pump (Fig. 3) was mounted on the wall to the left of the exhibit.

As mentioned above, before visiting the museum, the students had completed a number of experiments related to the physical laws governing pressure, temperature, and boiling point. This meant that they had some experience of conceptual issues related to how a heat pump works and at least some ideas about energy transfer, which was the main point addressed by the heat pump exhibit.

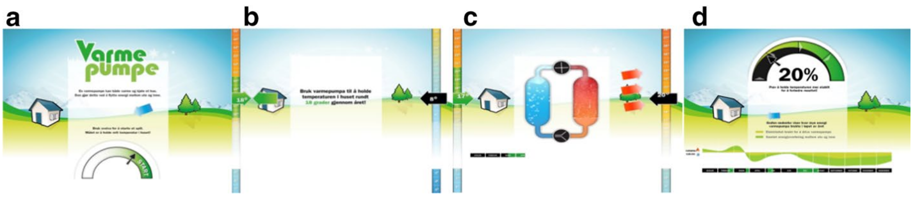

Fig. 2 **a** Start screen, **b** intro screen, **c** game screen, **d** result screen

Heat pump

Heating and cooling of buildings demands enormous amounts of energy. In order to cut energy consumption, it is of crucial importance to find more efficient ways to do this.

A single heat pump can both warm up and cool down a house by moving heat between the house and its environment. A heat pump uses only 1/3 of the energy of an electric panel heater.

Fig. 3 Heat pump poster

Participants

A class of 32 first-year Nordic high school students (aged 16–17 years) participated in the study, working on the project for 9 days during a 4-week period. The students were divided into groups of five or six. Four of the six groups were selected for tracking, and all their activities were video-recorded. In design-based research projects, the data collection phase is critical because data are available only during the project period, and it is important to ensure that these are of high quality. For this reason, it was important to avoid recruiting students who were either shy or overly active, and the teacher was involved in selecting the groups. To strengthen the validity of the data, there were two inclusion criteria: willingness to talk and ease with group work. The teacher suggested four groups but argued that this would make no difference because the groups were appropriately balanced, and this was confirmed over the 4 weeks of observation. On that basis, we argue that the participating students were typical of students in that class and school district in terms of social competence and academic achievement.

During the field trip, the students were equipped with iPods and iPads, which were inscribed with tasks to scaffold sense making at the science center, along with other tools to document their experiences and task solutions. Although we did not specifically analyze these activities, it is reasonable to believe that these tasks to some extent framed the students' talk and interactions with and around the exhibit (see Bakken and Pierroux 2015).

Data and analysis

To study the influence of different facilitation conditions on sense making towards conceptual learning in a science center, we analyzed video footage capturing how students, teachers, and guides talked and interacted with and around the heat pump exhibit. This activity took place on the fourth day of the project. To ensure data quality, we fitted each student and moderator with a high-quality remote microphone synchronized with the video camera.

All three groups engaged with the exhibit for about 10 min, and all talk was transcribed to analyze students' engagement under three different facilitation conditions: (1) peer-supported, (2) teacher-assisted, and (3) museum guide-facilitated. To analyze the selected sequences in detail, we applied methods from interaction analysis (Jordan and Henderson, 1995), enabling in-depth examination of students' actions, how these evolved from moment to moment, and how different previous experiences and future expectations became relevant within a relatively brief time. Here, we investigate variations across the three conditions and how the students in the three groups made sense of the exhibit. Episodes of talk and interactions were translated into English and transcribed using a modified version of Gail Jefferson's (2004) conventions (see "Appendix").

Students' sense-making and the heat pump exhibit

All three groups were able to play the game-based interactive heat pump exhibit, and all understood that the game elements visualized knowledge as part of the game. However, sense-making of the knowledge represented proved challenging for all three groups, and it was difficult for them to make this become conceptually oriented.

Peer-supported group

Interaction patterns in the peer-supported group indicate that the students were struggling to understand different features of the game at a conceptual level. They played the game several times, trying to achieve high scores and to make sense of the visualizations. The sequence of interaction selected for closer analysis illustrates this struggle; it is the only instance in which a curricular concept (evaporation) was used as a resource for collaborative reasoning about the exhibit. Analyzing this sequence shows how the group collaboratively oriented towards scientific concepts as a result of interacting with the exhibit.

As the sequence begins, the group of five students are testing the interactive heat pump game. One of the students reads aloud the introductory text that appears on the screen: "Use the heat pump to maintain 18 degrees in the house." Another student reads "You can warm up or cool down the house by shifting direction on the crank." This creates a frame for the activity by telling the students how to play the game and what types of actions are needed. The students take turns playing, and most achieve quite low scores. The group is having trouble maintaining a stable temperature in the house during different seasons. In addition, they orient to conceptual issues on only one occasion; in Excerpt 1, Student 1 is controlling the crank and says that the game is difficult to understand, prompting a conversation about how it works, what the students are experiencing, and how it may relate to conceptual issues. This sequence of interaction occurs during gameplay halfway into the episode. (The group scores 47%.)

Excerpt 1: Peer-supported group

Student 1:	No (0.6) I don't understand this? ((turns the crank as she plays the game))
Student 2:	Me neither (0.3) but now it is the same temperature in a way (0.1) almost the same temperature. ((moves her hand over the monitor screen from one side to the other))
Student 3:	What is this supposed to tell us? ((points at the screen))
Student 2:	((raises her shoulders to signal that she does not know the answer))
Student 4:	How difficult it is [to keep a house warm?
Student 1:	[E::: I kill the house?
Student 5:	Like how the thing works then you must look at the illustration (0.2) how?
Student 3:	Yes but I do [not understand x x

11	Student 2:	[Yes, or if the body temperature plays a role?
12	Student 4:	[It depends on how much x x (0.5) when its (0.2) temperature
13		here (1.0) changes then the temperature here must like keep
14		this temperature?
15	Student 3:	Yeah but what happens (0.1) I heard something about evaporation an:::d?
16	Student 1:	Hey I managed forty seven percent right. ((raises her hands up in the air))

When Student 1 says that she is unable to adequately engage with the exhibit (line 1), Student 2 responds that she also found it challenging (line 2). However, although Student 2 does not fully understand how to play the game, she comments aloud that she noticed that the temperature can be the same on both sides of the house (lines 2–3). This is a crucial observation because it potentially refers to energy transfer. Student 3 follows up on this and orients the rest of the group to the fact that representations in the game have specific meaning potentials. He uses the verb *tell* with emphasis, indicating that it may provide them with important information about the processes simulated by the game. However, this orientation to conceptual aspects is not picked up on or further unpacked by the other students. It is acknowledged, however; Student 2 shrugs her shoulders, gesturing that she does not have an answer (line 6), and Student 5 points to the illustration of the heat pump as a potential knowledge resource (line 9). Student 3 indicates that he is aware of the illustration but does not understand what it means (line 10).

Two utterances between lines 6 and 9 illustrate that Student 4 has understood that the aim of the game is to keep the house warm (line 7), but she feels incompetent as a game player ("How difficult it is"). Student 1 follows up and jokes "I kill the house" (line 8). Such remarks can be interpreted as part of the student's gaming language from leisure activities, which becomes a resource in making sense of this game-based exhibit. In many computer game genres, an important objective in games is to avoid being killed by enemies. By crying out "I kill the house," Student 1 positions herself as a person familiar with the activity of gaming and brings this reference into the process of making sense of the game. Student 2 wonders about a link between body temperature and the heating of the house (line 11) because, as part of the game, the player can feel the temperature change on the Pelletier Hands when turning the crank. This is a result of the heat transformation in the game, and the students' body temperature cannot influence this. What is interesting is that when Student 2 intuitively suggests this possibility, she opens up interpretations beyond the game design.

Picking up on Student 2's initial comment on temperature (lines 2–4), Student 4 orients the others to an important aspect of the game: that the temperature has to be kept stable in the house by the player (lines 12–14). This utterance may have been motivated by the introductory text shown when the game started and/or his experience of playing the game. However, this relates primarily to the game's objective and becomes more conceptual only when Student 3 again questions "what happens" (line 15). In attempting to make sense of the principles visualized in the game, he refers to "hearing something" about *evaporation*. They had already been introduced to this concept by the teacher at school while working on experiments related to physical laws of pressure, temperature, and boiling point. However, this is not picked up on by the other students in their talk, and they persevere with the game without linking it to conceptual aspects of the visualization. Student 1 ends the episode by sharing her new high score (line 16).

Summary of the episode

The students drew on different resources in their collaborative attempt to make sense of the exhibit. Their framing of the activity in a conceptual direction relied on information in the poster and in the game itself, and on their capacity to draw on prior knowledge developed during the relevant experiments at school. While the group understood that the game elements represented knowledge visualized as part of the game, translating this knowledge into conceptual learning of the relevant scientific principles proved challenging. The fact that the students had trouble keeping the temperature stable in the house during different seasons does not necessarily mean that they failed to understand the conceptually oriented content. However, the students did not make the concept of energy transfer relevant in their attempts to make sense of the activity. It is difficult to say whether this reflects the complexity of a game design combining analogue and digital tools, the complicated nature of the concept, or a lack of facilitating questions. Further, it is evident that the students had difficulty finding resources that would mediate formulations of more conceptually oriented questions and answers to make better sense of the exhibit. The questions they raised were not answered, and their perceptions of different features in the exhibit (the powerful visualization, the crank, and the Pelletier hands) were assigned equal importance in terms of meaning potential.

Teacher-assisted group

The teacher guided the students through gameplay and facilitated reflection on conceptual issues related to the heat pump. Alternating between support for student game play and achieving a good score, the teacher guided reasoning about what was happening in the game and what features meant conceptually. The selected sequence of interaction serves as a clear example of how students and teacher tried to reason collaboratively about what happens in the game and in a heat pump. The sequence also shows how the teacher used resources in the game to facilitate reflection about energy transfer. In addition, the teacher reframes the interaction to redirect students from playing the game to more conceptual and scientific aspects of the exhibit.

As the episode begins, the students are reading about the function of heat pumps from the poster next to the exhibit: “A single heat pump can both warm up and cool down a house by moving heat from between the house and its environment.” In contrast to Group 1, Group 2 begins the game without reading aloud the instructions displayed on the screen. Instead, the teacher explains to the students the functions of the different visualizations and tools in the game. The students play the game a couple of times. The particular sequence of interaction analyzed below (Excerpt 2) also occurs just after a session of gameplay, halfway into the episode, when the result screen is displayed on the monitor. The students have achieved a decent score (75%), indicating that they understood the need to turn the crank both ways in order to regulate the temperature inside the house. The teacher acknowledges the students’ score and begins to prompt the students to reflect on the conceptual issues raised by the game.

Excerpt 2: Teacher-assisted group

17	Teacher:	But what is happening?
18	Student 6:	Yes, you need more energy during the winter?

19	Teacher:	Yes?
20	Student 6:	When it gets colder?
21	Teacher:	But why is it::: (1.5) so the heat pump must work harder right?
22	Student 6:	Yes.
23	Student 7:	Mm.
24	Teacher:	During the winter (0.5) but what happens during the summer then (2.3)
25		when it gets warm outside? ((points at the screen where the tree appears on
26		the image))
27	Student 6:	Yes.
28	Teacher:	What did you have to do then (0.2) with the heat pump.
29	Student 6:	>Take in energy and make it cold< (0.1) [I think? ((pulls his closed hand
30		toward himself horizontally and
31		opens it))
32	Teacher:	[Yes right (0.3) so?
33	Student 6:	Other way (0.2) opposite? ((gesticulates that she moves the crank clockwise))
34	Teacher:	Other way yes (2.1) what does the heat pump function as then?
35	Student 8:	Opposite.
36	Teacher:	Yes opposite (0.4) of heating that is?
37	Student 7:	Cooling-down.
38	Student 9:	Cooling.
39	Student 7:	Yes.
40	Teacher:	Mm? (1.7) and then the heat pump functions as a:::?
41	Student 8:	Air [con.
42	Student 7:	[Air conditioner.
43	Teacher:	Air conditioner, yes right?

At the beginning of the sequence, the teacher creates a specific frame for the activity by uttering “But what is happening?” (line 17), signaling that the group has now finished playing and must develop an account of how the game illustrates heat pump processes. Reorienting the students from the game to the conceptual aspect of the exhibit by posing an open-ended question, his framing allows the students themselves to choose what to focus on. In response to his request, Student 6 refers to how energy use depends on the season (line 18). While the teacher simply says “Yes?” to confirm this, the rise in intonation signifies that he is not satisfied with this account, prompting the student to elaborate (line 19). When the student does not respond adequately by the teacher’s standard (simply repeating her point in a different way), the teacher picks up on Student 6’s utterance and orients the group to the issue of why more energy is needed, supplying the information that “the heat pump must work harder” (line 21).

Then, something very interesting happens. In lines 24–26, the teacher shifts the focus to what happens during the summer. The students do not respond to this question, saying only “Yes.” However, by focusing on how the temperature shifts from cold to warm, the teacher is able to use the game actions to orient to their embodied experience: “What did you have to do then (0.2) with the heat pump?” (line 28). This question enables the students to link to what they did during gameplay, and to provide an account based on their experience of turning the crank to reverse the heating process (line 29). “Take in energy” refers here to the air. When the teacher confirms this response but also signals that the student must elaborate, the student orients to the embodied and material aspects of the game and responds that they had to turn the crank in the “opposite” direction or the “other way” (line 33). The teacher then follows up and invites them to consider the opposite of the process they have just described, focusing the students on the process of cooling down. By the end of the sequence, the students are able to articulate a response emphasizing the multiple functions of the heat pump—that the device can be used as both a heat pump and an air conditioner (lines 41–43).

Summary of the episode

In this sequence, the teacher's contributions served to frame the students' efforts to make sense of the principles of the heat pump. The teacher guided the students in developing an understanding of how a heat pump works by referencing their experience of modeling its operations and linking the crank to the conceptual issue of heat pump versus air conditioner. He brought his teaching experience into play by posing open-ended questions with a clear focus. In so doing, he invited the students to engage in a dialogue centered on connections between the game experience and the functioning of the heat pump. In this way, the group's talk and game experience became resources that mediated the students' sense making and created an embodied sense of the phenomenon. The explanation focused on energy transfer, which is crucial to understanding how heat pumps function. Ideally, the teacher and students would have developed further connections between the content of the exhibit and scientific concepts previously discussed in the classroom, such as evaporation and condensation. Nevertheless, they appeared satisfied with their answer.

Group facilitated by a museum guide

This last interaction pattern shows that the guide did not monitor students during gameplay but prompted them after playing and facilitated reflection on conceptual issues. The analyzed sequence, in which the guide started to scaffold the students just after playing the game, was chosen as a clear example of how students and guide reasoned collaboratively about what happens in the game and in a heat pump, and how the guide used resources in the game to scaffold reflection. In addition, it shows the guide's attempts to use the experiments conducted at school as a resource, creating links between sense making experiences at school and in the science center. Analyzing this sequence reveals how the guide facilitated reflection and used the students' prior experiences as a resource in scaffolding conceptual learning of the exhibit. As earlier studies have emphasized the importance of building on prior experiences during conceptual learning (Sawyer 2006; Silseth 2018; Rosebery et al. 2010), it is interesting to see what happens when a facilitator taps into those experiences.

As explained above, the students had conducted a number of experiments before the field trip on physical laws and principles related to energy transfer and how a heat pump works, and the guide was aware of these pre-visit classroom activities. One of the experiments involved a spray can filled with liquid gas; the assignment was to explain "what happened" on spraying with the can. The students experienced that the can felt cold, which was a consequence of reduced pressure inside the can and the transformation of liquid into gas. The guide referred to this experiment to orient the students to reflect on these more conceptual issues as represented by the game visualizations.

While the group consisted of six students, only three participated verbally in this conversation (Excerpt 3), which occurs just after the first session of gameplay. As the sequence begins, the guide is commending the group for obtaining a high score (80%). He follows up by asking some questions about what happened during gameplay, and what it meant. As this sequence is rather long, we have excluded parts of the conversations to focus the analysis, marking the extractions in the transcription.

Excerpt 3: Guide-facilitated group

44	Guide:	Very good (0.2) could [I just ask you a question.
45	Student 10:	[x x
46	Guide:	If you all three (0.3) when you looked at the screen here (0.4) then you
47		saw that one part of the heat pump was blue (0.1) and then it was one part
48		that was red.
49	Student 10:	Yes.
50	Guide:	Did you see if they changed [when you changed?
51	Student 11:	[Yes?

((The teacher and students continue to talk about the blue part and the teacher refers to the spray can experiment at school and the students explains that the can became cold))

68	Guide:	The blue part (0.2) it occurred towards the house when it was ((the "start
69		screen" can be seen on the monitor and he puts his hand on the house on
70		the image)) (0.7) summer outside. ((puts his hand on the opposite side of
71		the monitor where trees can be seen))
72	Student 10:	Yes?
73	Guide:	And what do you then do to the house? ((puts his hand back on the house
74		on the image))
75	Student 10:	You warm no you ta::ke out. ((gesticulates that he pulls something
76		upwards))
77	Guide:	You co:::ol it down. ((holds his fist out in the air))
78	Student 10:	Yes.
79	Guide:	And what happened to the spray can (1.4) it got? ((refers to the spray can
80		experiment performed at school))
81	Student 10:	It got [co
82	Guide:	[Cooler.
83	Student 10:	Yes.
84	Guide:	Which process happens in that spray can (0.5) when it goes from::: from:::
85		steam to liquid.
86	Student 10:	I::t (0.5) oh.
87	Guide:	<Con>? ((laughter))
88	Student 10:	[Yes it condenses?
89	Student 12:	[Condenses?
90	Guide:	Condensation yes (0.2) yes (0.3) so the blue part (0.4) of the heat pump
91		((holds his hand over the area on the monitor where the house can be seen))
92		0.5) that is then (0.1) condensation (0.4) while the red part (0.3) what is
93		the opposite of condensation?
94	Student 10:	Evaporation?
95	Guide:	That is evaporation yes.
96	Student 10:	Yes?

97	Guide:	So when you turned (0.3) that movement ((gesticulates that he turns the
98		crank to the right)) what did you then do with the heat pump?
99	Student 10:	Turned (0.1) the positions (0.1) in order for it to become[:::? ((moves the one
100		hand from side to side horizontally))
101	Guide:	[Tu:::rned the circulation of heat
102		((moves his hand in circular
103		movements))

This sequence of interaction illustrates how a different expert in the knowledge domain framed student interactions with the exhibit. As the episode opens, the guide is posing quite specific closed questions about how visualizations in the game-based exhibit represent conceptual issues related to how a heat pump works (lines 44, 46–48, and 50). By emphasizing the word *blue*, first in line 47 and then in line 68, he makes the students aware that this aspect of the exhibit is important. (The blue part is a symbol for cooling the air.) He links this semiotic feature (color) to temperatures in a specific season. During the summer, it is hot, and when the guide asks the students "…what do you then do to the house?" (line 73), student 10 realizes that the preferred answer ("You warm no you take out" (line 75)) has to do with taking heat out of something. The guide reformulates student 10's account and orients it to the process of cooling (line 77). In these initial interactions, the guide actively refers to different visualizations in the game-based exhibit (such as the house depicted on one side of the screen and the trees depicted on the other) as resources for orienting the students to how heat pumps can also be used for cooling the house during warm periods.

When student 10 acknowledges the concept of cooling, something interesting happens. The guide links this understanding to more advanced scientific concepts by referring to their classroom experiment with a spray can (lines 79–80). By orienting to the concept of condensation, the guide attempts to build on the students' previous knowledge from the school setting. Student 10 begins to answer the question about what happened to the spray can in this particular experiment (line 81); the museum guide completes it (line 82), and student 10 follows up to confirm without elaborating further.

The guide has thus altered the focus to some extent. Having asked only what happened to the spray can, he focuses in the next turn on "which process happened" (line 84) in the can when the contents were transformed from "steam to liquid" (line 85), again orienting the students to more conceptual aspects of the exhibit and the prior experiment. However, when the students are unable to make this connection (line 86), the guide begins to spell out the first letters in the concept (line 87), and student 10 remembers the term (line 88) while student 11 contributes actively to the talk for the very first time by questioning the term (line 89). The guide then makes a link between representations in the game-based exhibit ("the blue part") and the process of condensation (lines 90–93). Furthermore, he makes the students aware that the red container in the game represents the opposite process. When the guide asks the students what the opposite process is, student 10 gives the correct answer (line 94), which the guide confirms (line 95). Finally, the guide orients to more embodied aspects of the game-based exhibit—specifically, the crank, which can be used to influence the direction of the air (lines 97–98). When the students respond to the question of what happens when the crank is turned, the guide, in his eagerness to scaffold the students' reflection, interrupts Student 10 to conclude "Tu:::rned the circulation of heat" (line 101).

Summary of the episode

The guide carefully facilitated the students' sense making, framing the activity in terms of key concepts and principles related to energy transfer and how it happens. However, the manner in which he framed the students' sense making activity differs from the teacher in Episode 2, as he *initiated* the interaction with more closed yes/no questions. The guide used resources in the game and the students' prior experience to make connections between prior knowledge and conceptually oriented learning in science. In addition, he was more oriented than the teacher to conceptual issues represented in the game, directing the students' focus toward two concepts in particular: evaporation and condensation. At the same time, the museum guide's pedagogical approach also introduced a more fixed interpretation, rendering the students' interactions more peripheral. Rather than sharing reflections in a dialogical way, they were used to confirm the guide's interpretations and explanations. This is interesting because it echoes previous evidence that linking to prior knowledge may not suffice to facilitate conceptual understanding. Transforming knowledge into relevant resources is also an issue of dialogical scaffolding, enabling students to question and explore conceptual issues in greater depth by ongoing assessment of their current level of understanding. As the guide's questions were often closed, the students ended up confirming predetermined "correct" answers and suggestions rather than collaboratively reflecting on and elaborating each other's interpretations. Consequently, it remains unclear whether the students shared the guide's understanding of condensation and evaporation or simply remember that these two concepts are linked, without being able to explain what they mean. The guide posed a more open question at two points in this episode (lines 47 and 72), and it is interesting that the students immediately began to reflect more openly (lines 49 and 73). It is also worth noting that, with the exception of one instance, only one student was active in the talk, making it impossible to reliably interpret the quality of the other students' sense making of the conceptual issues. This may relate to the composition of the group; as discussed earlier, the quality of students' uptake during facilitation depends both on the quality of the facilitation and on how well the students contribute to and make sense of the pedagogical and conceptual contributions offered by the facilitator.

Discussion

This study has examined how a group of students interacted with a game-based exhibit under three different conditions for scaffolding: (1) peer-supported, (2) teacher-assisted, and (3) facilitated by a museum guide. The analysis above addressed research questions related to conceptual orientations in the respective contexts, and the role played by the game-based resources inscribed into the interactive exhibit. In this section, we look across the three conditions to reflect more broadly on how the activities were framed by the participants, and we 'diagnose' the ways in which conceptual learning was scaffolded, or not, through talk and interactions with the exhibit. We conclude by considering how scaffolding may be designed to respond to the challenges we have identified, and by reflecting on the implications of this study for science center education.

Facilitation frames

The concept of frame provided us with the opportunity to examine what aspects of the facilitation conditions provided guidance for the students on how to participate (Silseth and Arnseth 2016). Linking conceptually oriented talk to previous experiences and knowledge is known to be particularly important in fostering conceptually oriented learning in museum settings (Gutwill and Allen 2012) and in (science) learning more generally (Linn and Eylon 2011). However, as the analyses show, such links can be difficult to establish or elaborate during sense making. For example, although the guide tried to build on students' previous experiences from school experiments, it proved difficult for them to relate heat pump functions to energy transfer and processes of evaporation and condensation, neither of which was explicitly mentioned in the interactive game. Similarly, while the peer-supported group referenced the concept of evaporation and previous experiences at school, this was not picked up, elaborated on, or used as a resource to frame their understanding of the game and the heat pump's functions at a conceptual level. In sum, the problem of gap-closing and transferring existing knowledge to new settings remained challenging in the peer-supported and guide-facilitated conditions. In the teacher-assisted group, the students' uptake of the teacher's initiative to frame the activity developed differently. By inviting the students to reflect on and interpret the game-based exhibit and the curricular issues it might address, the teacher contributed by framing the activity as related to their experiences and observations of the science exhibit rather than the classroom. The teacher-assisted facilitation was more successful in orienting the students' ideas and framing of the activity toward a conceptual level.

Dialogic scaffolds for conceptual learning

In all three groups, knowledge issues were raised in talk that was somewhat question-oriented, but the question-oriented activity unfolded differently across the groups. While the student 'leader' in the peer-supported group and the teacher in the teacher-assisted group posed open-ended and conceptually oriented questions, the guide asked more closed questions in the group he facilitated. However, the open-ended questions in the peer-supported and teacher-assisted groups led to different outcomes. In peer-supported group, the student leader's open questions about knowledge issues were not followed up, other than being vaguely acknowledged as challenging to understand. This aligns with previous findings that students when unaided find it difficult to make sense of conceptual scientific issues, even in cases where they manage to perform an activity like getting a hot air balloon to take off (Achiam 2012). Performing the activity is no guarantee for being able to scientifically explain what happened. When the teacher asked similarly open-ended questions, building on his classroom teaching experience of supporting inquiry-oriented processes, the students engaged more deeply in the knowledge issues that emerged. Our interpretation of the differences between conditions, then, is that the students on their own did not have the capacity to formulate the questions and conditions for inquiry. Discussions of conceptual issues were thus limited in the peer-supported condition, with the exception of one student's initiative in questioning what the game-based resources "mean." As identified in previous research, the contingency for scaffolding designs in peer-to-peer facilitation conditions is to quite specifically support inquiry processes, e.g., 'worksheet' approaches that provide questions and procedures to guide a process as described and analyzed by James

Kisiel (2003) or crash courses in inquiry learning methods as proposed by Joshua Gutwill and Sue Allen (2012).

The teacher and the guide served as conversation catalysts in their respective groups (cf. Rosenthal and Blankman-Hetrick 2002), leading talk in a more conceptually oriented direction and arranging the conditions of seeing. Open questions and initiatives from the teacher allowed the students to make explicit links to conceptual issues, which is vital to guide sense making in a conceptual direction (Vygotsky 1978). As we have documented, these connections were not something they were able to mobilize by themselves although within the students' zone of proximal development. As both Hans Christian Arnseth and Ingeborg Krange (2016) and Janecke Van der Pol et al. (2010) have previously documented, students need explicit help to develop their conceptual understandings. The use of closed questions by the museum guide produced a more fixed interpretation than the teacher's approach, allowing fewer openings for conversational elaboration (Leinhardt and Knutson 2004). The students (usually one student) tended to agree with the guide's interpretations and explanations. This dialogic approach diminished the students' involvement, and although the talk was based on conceptual issues, it is hard to interpret what they understood. Like Tali Tal and Orly Morag (2007), we discovered that the guide did not really invite the students into an inquiry process by analyzing, synthesizing, generalizing, or evaluating new information. Our findings indicate that, despite the high level of student participation, the guide-facilitated dialogue was fact-oriented. This is not necessarily sufficient to stimulate students' sense making in a conceptual direction (Edwards and Mercer 1987), as facts need to be "unpacked, debated, and explicitly scaffolded for the visitor" (Knutson and Crowley 2009: 8). In sum, the contingency for scaffolding designs in teacher-assisted and guide-facilitated conditions is inquiry orientation that dialogically invites and includes students in conceptually oriented sense making processes. Accordingly, challenges for conceptual learning in science centers are similar to those that have been systematically identified and investigated in school settings over many years (Lazonder and Harmsen 2016; Linn and Eylon 2011).

Representational repertoire in exhibit designs

Our analysis established that all three groups of students managed to play the interactive heat pump game, and although scores varied, all understood that the game elements represented knowledge visualized as part of the game (Lehrer and Schauble 2010). The gameplay aspect of the exhibit propelled activity and interactions that proved important for all three groups. In the analysis, however, we identified variations in what Richard Lehrer and Leona Schauble (2010) called the "conditions of seeing," that is, how students, guide and teacher related to the game and how it was enacted as a resource for sense making. While peer-supported students had difficulty framing their activity as something other than gameplay, the other two groups used the game as a resource to talk about and support their sense making in a conceptual direction relevant to heat pump functioning. However, we note that all three groups needed to play the game several times before they were prepared to make sense of the more conceptual issues.

The analysis further showed that although the peer-supported group was aware that the visualizations represented and modeled heat pump functions, they found it challenging to employ gameplay as a resource for further knowledge development. This aligns with similar findings in studies of game-based learning in educational settings (Silseth 2012). Kenneth Silseth (2012) found that the teacher had a crucial role in orienting the students to conceptual issues during gameplay, and in facilitating dialogues that contributed to expanding students' understanding of complex issues raised in the game. This finding is also supported by Marianne Achiam's (2012) hot air balloon study mentioned above, where students managed to perform the activity (in our case, playing the game) but could not explain the scientific principles that the activity modeled or represented. For most of the peer-supported group, the game's aim framed the activity—that is, operating the heat pump so that the inside temperature of a house remained stable throughout the year, regardless of any changes in the outside temperature. In other words, it was possible to participate in the activity without making any conceptually oriented interpretations.

In the groups where interactions were facilitated by teacher and guide, respectively, the game was explicitly made relevant in conceptually oriented framings. This was accomplished by pointing to the screen or other features of the exhibit, referring to movements and gestures involved in manipulating models and representations, and linking these to the specific energy transfer processes and concepts being discussed. In line with previous research, we found that such facilitation deepened the student involvement in sense making processes (Ash and Lombana 2012). At a general level, then, our study supports previous findings that students need guidance when engaging with knowledge resources inscribed in exhibits of this kind if science centers and museums are to influence students' sense making of conceptual issues in alternative ways, including game-based learning environments. More specifically, in terms of designs for contingent scaffolding (Van der Pol et al. 2010), this study suggests including facilitation frames, e.g., peer-supported, teacher-assisted and guide facilitated, as conditions of seeing when working with representational repertoires for science center learning (Lehrer and Schauble 2010).

Concluding remarks

The aim of this targeted study is to provide insight into variations across three common facilitation conditions on field trips to science centers, thus contributing to discussions of how to provide contingent support for conceptual learning. Acknowledging the limitations of the study sample, which consists of three small groups from one class observed during a science center visit, the analysis shows some of the social and cognitive challenges that students face when attempting to make sense of game-based exhibits designed to demonstrate scientific concepts. Generally speaking, we found that orientation to conceptual issues depends on how the activity is framed and facilitated by a skilled moderator; it seems easier for groups supported by teacher and guide to differentiate between what is relevant and what is less important, explicating various actions and interpretations in their talk as part of their framing.

By including the game-based exhibit and other resources in our analysis, we were able to scrutinize at the interactional level how participants in the different conditions drew on material and representational features of the game to direct sense making toward conceptual issues. The analytical approach provides insight into how the meaning potential of an exhibit design has implications for sense making and potentially conceptual learning in science centers. In encounters with exhibits that are interactive and complex, scaffolding conceptual learning must support the need to almost *simultaneously act and reflect* on actions. While the peer-supported group did not move beyond interpreting the gameplay and related tools, the other two groups were able to use features of the gameplay (the crank and Pelletier hands) and the students' previous knowledge to mediate conceptually oriented interpretations.

Scaffolding sense making and conceptual learning among student groups is challenging in any setting, and there remains considerable potential to develop innovative pedagogical approaches in specific and situated science center contexts. Based on this study of three conditions for scaffolding, and on the extensive research on learning in science centers in recent decades, we nonetheless question whether it is possible for pedagogical designs in these settings to include ‘fading’ and ‘transferring responsibility for learning to the student’ in scaffolding intentions and means. Although these two characteristics are implicit in the definition of scaffolding (Van der Pol 2010), there is scant evidence to support scaffolding designs that aim to decrease contingent support during a field trip learning trajectory.

Finally, in line with Lauren Allen and Kevin Crowley (2014, p. 84), we argue that “educators in informal settings can be a key part of the learning experience”, and that it is surprising that “they are often poorly supported as professionals.” We acknowledge the need for programs that offer museum guides, teachers, and chaperones opportunities to increase their pedagogical knowledge of students’ sense making processes in science center settings. It also seems essential to examine the implementation of facilitation programs for different student groups (by size, age, and gender) and exhibits (by design, complexity, and theme) to sustain best practice communities among educators in informal learning settings. We know that some scaffolding initiatives foster sense making in conceptual directions better than others, but at the same time we know that there are no ‘one size fits all’ solution for these activities. More knowledge of how different student groups respond to best practice scaffolding is needed.

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Appendix: Transcription conventions

Sign	Explanation
(2.5)	Time interval between speech in tenths of a second
< >	Right and left carats indicate that the talk between them was speeded up or slowed down
that	Underlining indicates emphasis on words and expressions
[	Bracket indicate where overlapping talk starts
:::	Colons indicate a lengthening of the word or sound
. ?	Punctuation markers indicates intonation. Question-mark indicates rising intonation. The period indicates falling intonation
x	This indicates a word or sound that is difficult to hear
((looks up))	Sentence that appears within double parentheses describes action

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