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Article

Strengthening Science Understanding with Learning Trails

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Abstract: The Norwegian Museum of Science and Technology have developed a learning concept for school classes in science centres named 'learning trails'. In this concept, groups of students perform a series of thematically related experiments with installations in the science centre. The learning trails are designed to support the generic learning outcomes for science centre visits. We argue for using the previously developed Engagement Profile in an indicator to determine both media forms and generic learning outcomes for such learning concepts. Further, we implemented the learning trails in two modes: one mode used paper-based content to guide the students, while the other mode supported the use of tablet PCs where engaging content is triggered when the students approach the location of an experiment in the learning trail. We studied the engagement factors of the learning trails and observed how school classes use these. In a study with 113 students from lower secondary school, they answered short questionnaires that were integrated into the implementation of the learning trails. While the concept of the learning trails was evaluated positively, we could not find significant differences in how engaging the two implemented modes were.

Keywords: learning trail; science centres; visitor engagement; generic learning outcomes

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1. Introduction

Science centres are informal learning environments [1] that offer exhibits supporting free-choice learning, as well as specific programmes for organised school class visits. We want to explore to what degree such learning programmes engage students and find means to strengthen the engaging factors of an exhibit [2].

The Norwegian Museum of Science and Technology (NTM) introduced the concept of learning trails around science centre installations grouped thematically. The learning trails combine physics experiments with technology history from the exhibitions in the science centre. The motivation for this is to foster learning from using these installations and to create dialogues and narratives [3] that explain science phenomena. The activities of the learning trails are designed for groups of up to four students at a time.

The objective of this paper is to explore how the elements in the learning trail concept can be used to create engaging content that supports the generic learning outcomes [4] specified by the science centre. We relate the Engagement Profile [2] to the generic learning outcomes and evaluate the learning trails in an empiric study with students from secondary school classes. Further, we investigate the impact of presenting location-based content on a tablet PC versus a paper-based version of the learning trails. To study this, we implemented a prototype that presents content upon arrival at an experiment, using unobtrusive and affordable in-door location technology.

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In the following, we present an overview of related work including a review of learning outcomes, the Engagement Profile, and location technology in museums and science centres (Section 2), before we show how to translate the Engagement Profile to terms related to media forms and learning outcomes (Section 3). Thereafter, we present the concept of the learning trails and their implementation (Section 4) and develop the Engagement Profiles for the learning trail concept and the single experiments, before deriving the related media forms (Section 5). Section 6 presents an empiric study where the prototype of the learning trails was evaluated with students from secondary school classes. Section 7 concludes our essay.

2. Related Work

We focus on school children visiting science centres as a class activity as the main target group for our work. As these students may have diverse learning agendas and prefer diverse ways of learning (such as reading, interacting with others, touching and doing) [4], science centres offer a diversity of exhibits that can be explored during the visit. The design of installations [5] should address factors such as the targeted learning outcome, learning styles, levels of engagement, and context.

2.1. Learning Outcomes in Science Centres

Learning outcomes in science centres are difficult to specify and to measure, even if we consider the compulsory participation of school children. The pedagogical tool Generic Learning Outcomes (GLO) [4] describes the impact of learning in museums in terms of a) knowledge and understanding, b) skills, c) change in attitudes and values, d) enjoyment, inspiration and creativity, and e) activity, behaviour and progression. These five aspects cannot be used as guidelines to control the design process of exhibits, as these aspects are yet unrelated to design properties. However, we note that design and implementation elements will have a considerable impact on the GLO. Therefore, we seek a way to predict how changes in design and implementation will impact the GLO.

Brown [6] remarked that the GLO are subjective, do not measure learning directly, and are most effective as post hoc measures, that is, after the learning experience. He suggested to consult Laurillard's taxonomy of educational media [7] that is based on the teacher's concepts and constructed environment, and the student's concepts and specific actions. The four kinds of activities in her framework are: discussion, adaptation, interaction, and reflections. Unlike the GLO, Laurillard's framework is not specifically developed for science centres, and adjustments for its use in science centre learning might be necessary.

In Laurillard's framework, the related learning experiences and adjacent media forms (in parentheses) are: i) attending, apprehending (narrative); ii) investigating, exploring (interactive); iii) discussing, debating (communicative); iv) experimenting, practising (adaptive); and v) articulating, expressing (productive).

As all five learning experience types and media forms are present in science centre learning, Laurillard's framework can be applied to exhibits in science centres. However, these learning experiences are present to a varying degree in each exhibit or concept. Experimenting and practising, as well as investigating and exploring are the most prevalent forms of experiences, while specific concepts, such as the learning trails, can extend learning to other learning experience types. Notice that the work by Laurillard [7] and that by Brown [6] were published before many of the current media technologies were introduced in science centres; thus, the methods and technologies described there might be somewhat outdated and could need adjustment.

The GLO are used as a basis for evaluations in science centres and museums. For instance, Ayudhya and Vavoula [8] use the GLO to guide the design of questions about the outcomes in an assessment of a mobile app used by families in a science museum. In their analysis, they also encode observations captured on video according to Bitgood [9]'s attention-value model, that comprises of the actions: capture, focus, and engage (and an extra class: engage together [8]). Visitor observations and

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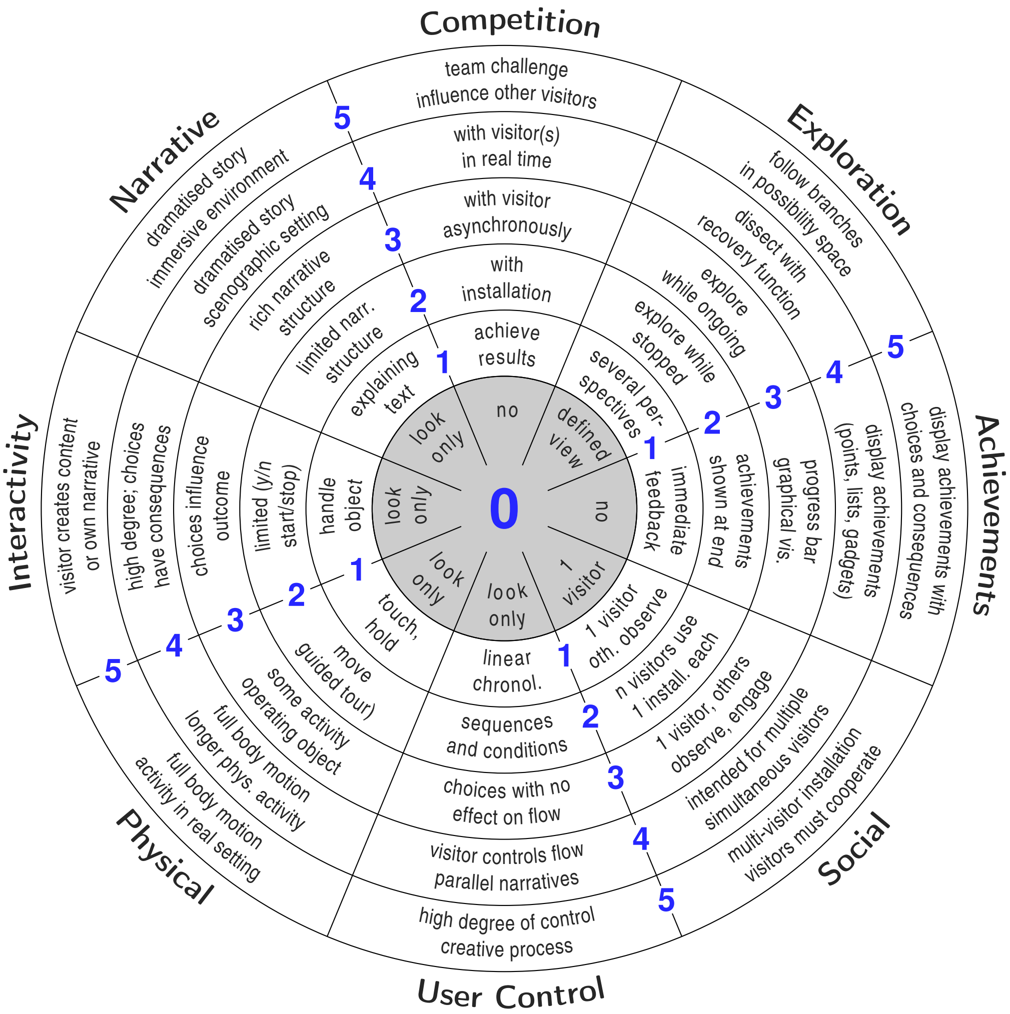

Figure 1. The dimensions of the Engagement Profile explained with short definitions. To define the value of a property, find the adjacent number of the phrases that fit best.

encoding activities belong to the visitor-centric view of assessment. In contrast, we want to focus on the installation-centric view that is discussed by Leister *et al.* [2, p.51]).

2.2. Quantitative Evaluation of User Engagement

Behavioural engagement is one of the factors that has a positive correlation to achievement-related outcomes [cf. 10, p. 70ff]. In informal learning arenas, this implies that engaging exhibits and installations will foster better learning outcomes than exhibits that do not engage.

To evaluate how engaging installations are, the Engagement Profile [2] has been used alongside with sensors, observations, and questionnaires to measure engagement and user satisfaction. The Engagement Profile has been applied to the design process at museums and science centres [5], to analyse engagement and narratives for installations [3], and to develop a robotic teaching assistant for students at a university college [11].

The Engagement Profile quantifies the characteristics of installations along eight dimensions, each of which is given a value between 0 and 5. The dimensions of the Engagement Profile represent the degrees of *competition* (C), *narrative* elements (N), *interaction* (I), *physical* activity (P), *user control* (U), *social* aspects (S), *achievements* awareness (A), and *exploration* possibilities (E). A graphical presentation of the Engagement Profile is shown in Figure 1 as a reference.

External influences are not taken into account in the Engagement Profile since these are not properties of the direct learning environment. Physical factors, such as noise, light or smell could play a role in the perception of engagement, but need to be handled outside the Engagement Profile. Properties that belong to the context, such as social factors, institutional factors, or recent incidents personally or globally, are excluded. However, these factors still need to be taken into account in the assessment process, e.g., as suggested in the DEX-framework [12].

2.3. Location-Based Systems in Science Centres and Museums

We posit that engagement can be increased when offering tailored content based on the visitor's current location. Such location-based systems are commonly used as a component of installations, as well as part of visitor studies and exhibit evaluations [13]. Several authors [e.g., 14,15] suggest to adapt content to the visitor's current situation or to adjust the visiting path using on-line tracking. In our approach, we use on-line tracking to trigger engaging content based on the location of the visitor.

Location-based systems can be used to retrieve viewing times, itinerary, speed, group behaviour, and so on. Yalowitz and Bronnenkant [16] presented methods for visitor tracking and timing in museums. They classified the variables to be recorded into a) stopping behaviour; b) other behaviour; c) observable demographic variables; and d) situational variables. Further, they addressed practical issues, technology, and ethics to collect, analyse, and interpret these variables.

Baldwin and Kuriakose [14] presented several technologies for tracking visitors. Tracking data are used to a) predict a visitor's future path in the museum; b) recommend exhibits of potential interest to the visitor, and c) personalise content delivered to visitors. They also explored the impact of physical proximity and visitor gaze on exhibit engagement.

Yoshimura *et al.* [17] presented a study where they use Bluetooth proximity data of visitors' smart phones to measure the visitors' transition between places in a museum. Moussouri and Roussos [18] discussed cultural itineraries of visitors and present a study where outdoor tracking devices are used to extract the paths of visitors in the London zoo. Further, Moussouri and Roussos [19] proposed a methodology for representing location-based data collected by the use of smart-phones. They presented three ways: a) trail-based representation; b) functional representation; and c) statistical distributions of displacement.

The prediction of visitor's sentiments and future behaviour can be based on current observations. Parsons *et al.* [15] suggested to use viewing times as an indicator of preference, and they propose a recommendation system based on this idea. Bohnert and Zukerman [20] used viewing times as an indicator for interest. They proposed non-intrusive personalisation of the museum experience based on viewing times of previous visitor behaviour and evaluated two prediction approaches.

Besides outlining exhibit design approaches and strategies, Bitgood [21] presented three types of visitor measures of success: a) behaviour measures including stopping (attracting power), viewing time (holding power), social impact, human factors impact, and trace or decay measures; b) knowledge acquisition (memory, comprehension); and c) affective measures (attitude change, interest level, satisfaction).

2.4. Indoor-location Technologies

In-door location can be used both for analysis, and to adapt and control the stream of content to the visitor. Mautz [22] presented a variety of indoor-tracking systems based on ample technologies. Lymberopoulos *et al.* [23] compared indoor-location technologies that are based on WiFi, geo-magnetic, sound signals for the infrastructure-free technologies, and RF-beacons, RFID, infrared, ultrasound, Bluetooth, short-range FM transmitters, lights, and magnetic signal modulators for the infrastructure-based technologies. Bickersteth and Ainsley [24] compared ample technologies for tracking using mobile phones in museums, such as use of the Temporary Mobile Subscriber Identity (TMSI), Bluetooth, and WiFi. In museums and science centres, we have also seen location approaches based on QR-codes and camera-based tracking [25].

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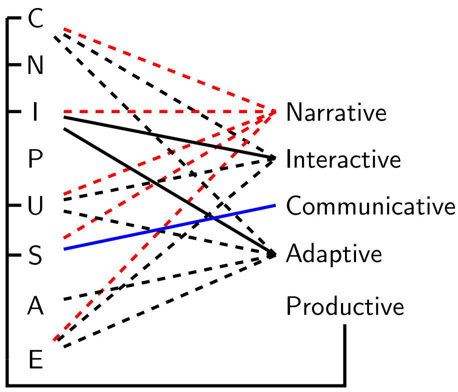

Figure 2. Aligning the entities of the Engagement Profile (left) with those of Laurillard's taxonomy (right). The dashed lines indicate partial impact. Colours are used for graphical clarity.

3. Generic Learning Outcomes, Media Forms, and the Engagement Profile

Learning outcomes depend on how students use the installations within the context of their science centre visit and how the installations and activities are designed. We have already outlined that the GLO define the outcome of a science centre visit, while Laurillard's taxonomy qualitatively describes activities and media forms for learning. In contrast, the Engagement Profile describes properties of exhibits quantitatively.

The implementation of an exhibit, characterised by the Engagement Profile, supports the learning outcome and the GLO through the learning activities in the science centre. Further, we posit that the media form can be described by the Engagement Profile. To support this claim, we relate the terms of Laurillard's taxonomy to the terms used in the Engagement Profile and define thresholds that indicate which media forms an exhibit has.

To create this indicator, we use the description of the media forms, adapted from the work by Brown [6] as a starting point. Further, we use the description of the Engagement Profile (see Figure 1 for the graphical short form). We create the indicator by evaluating which term in the Engagement Profile fits best to the description of the respective media form.

This results in the following findings: The variables C, I, U, and E have an impact on on the narrative, interactive, and adaptive media forms. We also observed that the productive media form requires several high values in the Engagement Profile. Further, P appears to be irrelevant to indicate the media form as defined in Laurillard's framework. The relationship between the Engagement Profile and Laurillard's framework is graphically shown in Figure 2.

By identifying which values of the Engagement Profile suit the description of the media forms, we are able to set up conditions for which media form a given exhibit potentially can have. These conditions and their respective thresholds are shown in Table 1. The media forms relate to the Engagement Profile as follows:

Narrative media forms are described to be linear, highly structured, and non-interactive. Interestingly, the entire range of N applies for this media form. To fit into the narrative media form, most values of C, I, U, S, and E need to be rather low, i.e., between 0 and 2. Values above the threshold of 2 need to be considered regarding their impact from case to case.

Interactive media forms allow learners to explore in a non-linear way, but the content remains unchanged. This description aligns with high values of I, E and U; however, values of 5 for these three variables are not suitable. Further, medium high or high values of S and E are suitable.

Communicative media forms support feedback and foster discussions, which indicates high values of S. The other variables do not have an impact here.

Adaptive media forms adapt responses to the student's actions. This is supported by high values of I, E, and A, and medium high or high values of U and C.

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Table 1. Engagement Profile indicators for media types

Laurillard's taxonomy activity	media form	Engagement Profile indicator
attending apprehending	narrative	$0 \le z \le 2$, for most $z \in \{C, I, U, S, E\}$; (N not significant)
investigating exploring	interactive	$3 \le z \le 4$, for most $z \in \{I, E, U\}$
discussing debating	communicative	$3 \le S \le 5$
experimenting practising	adaptive	$3 \le y \le 5; 2 \le z \le 5$, for most $y \in \{I, E, A\}, z \in \{U, C\}$
articulating expressing	productive	$4 \le z \le 5$, for several $z \in \{C, N, I, U, S\}$

Productive media forms are tools where learners can express themselves to demonstrate their understanding. This implies high values of C, N, I, U, and S.

In practice, supported media forms for a given exhibit can be estimated by first creating the Engagement Profile, that is finding the most suitable description in Figure 1 or by using the textual description in [2, p.56, Table II]. Thereafter, Table 1 is used to check whether the condition for each media form is met.

4. Learning Trails

The learning trails at NTM are designed for school classes. They combine physics experiments with technology history from the exhibitions, grouped thematically. To increase the learning effect, these installations are intended to create a wider dialogue and narratives that explain science phenomena. From the perspective of the GLO, increased knowledge and understanding are most important outcomes, while the visit at the science centre shall be enjoyable and inspiring.

NTM has organised learning objectives for subjects that have been discussed in class before the museum visit. Further, the museum also expected that students understand the task better when they, additionally, can listen to content from an audio file.

There are indications from earlier observations at NTM that the students will be more quiet when given organised tasks, instead of letting them explore the exhibits on their own. As in many science centres, noise from school classes in the exhibition area can be annoying. Therefore, the learning trails have been designed so that the single tasks are performed at different locations in the museum.

4.1. Concept of the Learning Trails

The learning trails are designed for self-experience in small groups of up to four students, lead by the teacher. The total activity in a learning trail is meant to last less than 30 minutes. Upon arrival, the students are divided into groups of up to four. Each group receives a set of experiments that the members of one group shall solve together. These experiments take place in the exhibition of the science centre and are related to exhibits (e.g., objects, boards, and pictures), installations, and areas where the necessary ingredients for the experiment are available.

Each group needs at least one smart device (smartphone or tablet PC) with the possibility to use Bluetooth for interaction with the beacon technology that provides the location service. The smart devices are used to present tasks and extra content. Alternatively, tasks and content can be handed out on paper.

The learning trails are compatible with the Bring Your Own Device (BYOD) paradigm, so that science centres do not need to distribute these devices to the visitors. However, NTM can provide such devices for school classes to avoid compatibility problems, as students might not have an own device or bring devices that are incompatible with the science centre's content and services.

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Table 2. List of experiments of the learning trails an reference to illustration image

learning trail	#	name	description, activity	Figure
"Forces"	#1	Pirouette	use installation, change speed through body movements	3a
	#2	Cup	cup, lace, pencil; does the cup break?	3b
	#3	C. regulator	observe model, watch video	3c
"Sound"	#1	Thunder	video: thunderstorm; count seconds: sound through tube	3d
	#2	Spoon	listen via medium air/laces: two teaspoons hit each other	3e
	#3	Vacuum bell	listen while pump makes vacuum around ringing bell	3f
"Light"	#1	Light-table	try out convex and concave lenses	3g
	#2	Letterboard	experiments with long- and short-sightedness	3h
	#3	Up-Down	observe projected image through lenses, film	3i

Each group performs the given tasks and experiments at the stations of the learning trail. Afterwards, all students participate in a quiz implemented with the Kahoot [26].

4.2. Implementation of the Learning Trails

So far, NTM has developed three learning trails that offer content on the physical phenomena of forces, sound, and light. Each learning trail has been implemented in two modes: I) the learning trail is paper-based; i.e., instructions to the participants are printed on laminated cards; II) the learning trail and its content are available on a device such as a smart-phone or tablet PC. This device will automatically push instructions and extra content (such as illustrating videos and audio) to the participants. The content is triggered as soon as the students approach the location of the respective experiment of the learning trail.

The indoor-localisation technology was implemented using beacons that are based on Bluetooth Low Energy (BLE). At each location of a learning trail experiment one beacon is placed. Actions are triggered by the proximity of the device (smartphone or tablet PC) to the respective beacon. The proximity level is classified into five zones A-E using the following thresholds: A: < 1m; B: < 2.5m; C: < 5m; D: < 7.5m; and E: above. Depending on characteristics of the installation, we assume that a participant is close by when being in Zone C, but for some exhibits Zone B is more appropriate. This can be configured per exhibit.

While the student groups perform the learning trails, the students' devices check the beacon proximity about once every second. Notice that too high sampling rates could drain the device for battery power.

4.3. The Experiments of the Learning Trails

Each learning trail consists of three experiments, which are performed according to a pre-defined schedule. In total, nine experiments have been developed, each of them described as a sequence of presentations, questions, and tasks to be performed by the student group. The experiments include discussions in the group to reflect on the subject of the respective experiment. Table 2 gives a short overview of these experiments, and illustrative photos taken during class visits are shown in Figure 3.

For the learning trail forces, the *pirouette* is an installation that can be used to explore rotation movements. The students are asked to use the installation and change rotation speed through their body movements (Figure 3a). *Cup* is an experiment where a cup is attached to a lace. Given the lace is led over a pencil and the cup is released, does it hit the ground? The students are asked to perform this experiment (Figure 3b). In a third experiment the students watch and discuss a model of a centrifugal regulator (Figure 3c).

For the learning trail sound, *thunder* is an experiment where the students watch the video of a thunderstorm, and they count the seconds from when they see the lightning until they notice the sound of the thunder through a long pipe (Figure 3d). *Spoon* is an experiment where the students listen to two spoons hitting each other through air and through a lace as a transmission medium (Figure 3e).

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(a) (b) (c)

(d) (e) (f)

(g) (h) (i)

Figure 3. Examples for the experiments in the three learning trails. Forces: (a)-(c). Sound: (d)-(f). Light: (g)-(i).

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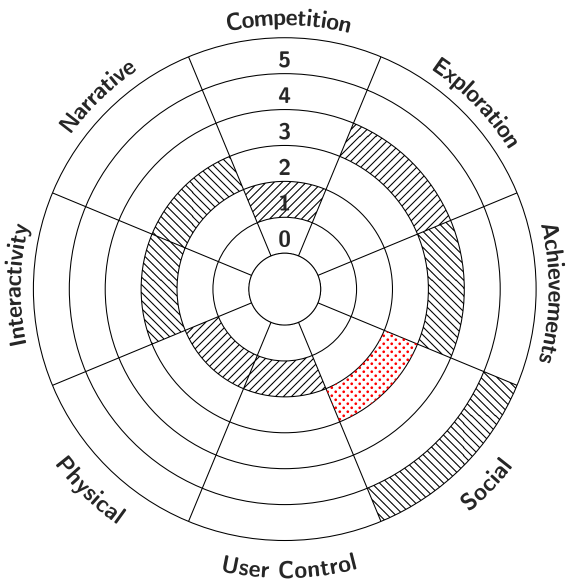

Figure 4. Engagement profile of a generic learning trail. The red dotted field indicates the S-value when the learning trail is performed as a single visitor instead of in a group.

In the installation *vacuum bell* a door bell is installed under a cheese dome, where a pump can generate a vacuum. The students shall observe when they stop hearing the sound from the bell (Figure 3f).

For the learning trail light, *light table* lets the students try out convex and concave lenses (Figure 3g), while *letterboard* provides experiments with long- and shortsightedness (Figure 3h). In *up-down*, the students observe a projected image through a set of lenses (Figure 3i).

5. Engagement Profile and Media Forms of the Learning Trails

For the analysis of the learning trails, we consider the Engagement Profile of the generic learning trail concept separately from the Engagement Profile of each experiment. In practice, we overlay the Engagement Profile of each experiment with the Engagement Profile of the generic learning trail. We also use the above described indicator to determine the media forms of the generic learning trail.

5.1. Engagement Profile of the Learning Trails

In Figure 4, we show the Engagement Profile of a generic learning trail. The values for each of the eight Engagement Profile dimensions are determined by considering which of the phrases in the description fits best. As this process is based on subjective considerations, we note the following: Since learning trails are usually performed in groups, we set the social dimension S=5 (for a single visitor S=2). Regarding the narrative (N) dimension, the learning trails are structured sequentially without the possibility for the student to alter this. Thus, we set narrative and user control to N=2 and U=1. The remaining values are set according to which phrase of the Engagement Profile definitions (see Figure 1) fits best for each dimension.

5.2. Engagement Profile for the Single Experiments

We created the Engagement Profile for all nine of the experiments by subjectively determining the phrase from Figure 1 that fits best. The charts for the experiments on forces, sound, and light, respectively are presented in Figure 5.

In the context of the learning trails, the Engagement Profile of the generic learning trail can be seen as an overlay for the Engagement Profile of each experiment. Note that some of the characteristics of the generic learning trail might be dominant over the individual rating. Thus, changing the characteristics

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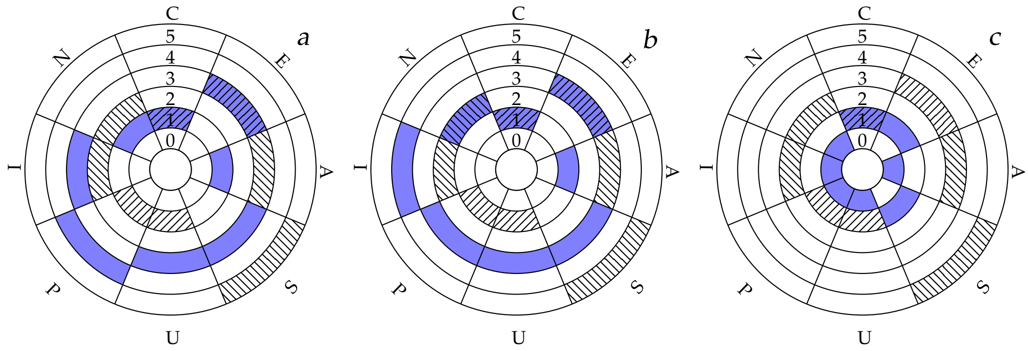
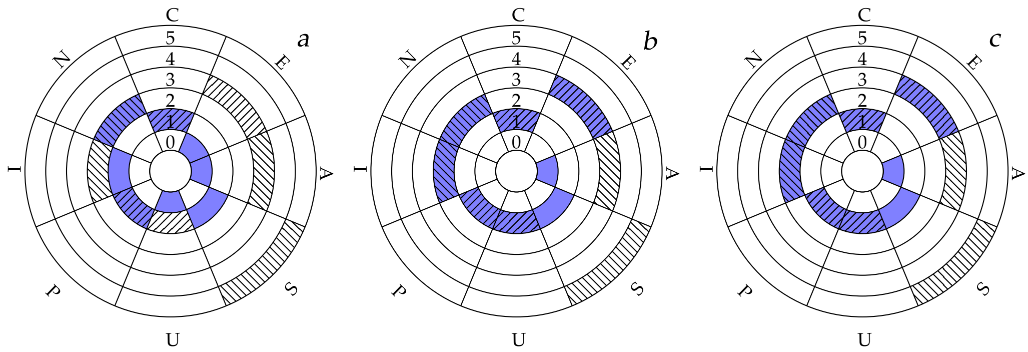
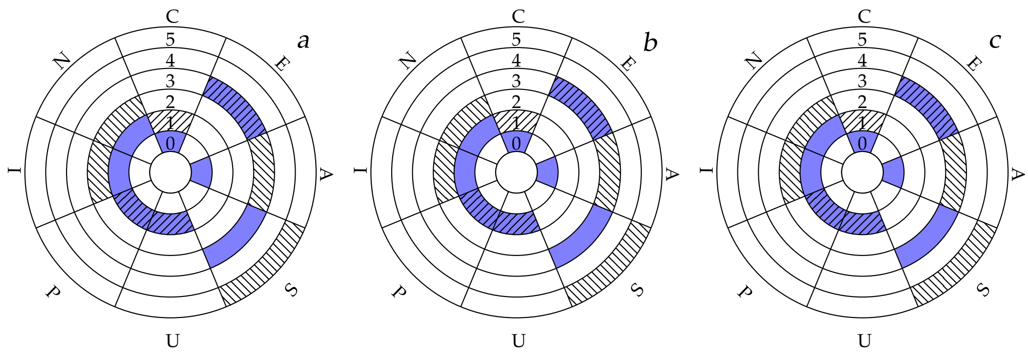


(a) Learning trail forces



(b) Learning trail sound



(c) Learning trail light

Figure 5. Engagement profile of the three experiments in the three learning trails (blue marking are for the respective experiment, hatches are for the generic learning trail).

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Table 3. Media form evaluation of generic learning trails. Relevant parameters are marked with ✓ if condition is met and with ✗ else. Unmarked entries do not have an impact according to Table 1.

media form	C	N	I	P	U	S	A	E[a]	decision
Narrative	✓		✓		✓	✓[b]		✗	✓
Interactive			✗		✗			✓	✗
Communicative						✓[c]			✓[c]
Adaptive	✗		✗		✗		✓	✓	✗
Productive	✗	✗	✗		✗	✓[c]			✗

[a] impact is not considered to be relevant for learning trails.
[b] if visitor is alone.
[c] if visitor is in group.

of a single experiment might not have an impact. For instance, increasing the social dimension for a task might not have an impact, as the social dimension of the generic learning trail is already high.

5.3. Media Forms of the Learning Trails

Using the Engagement Profile of the generic learning trail and the translation in Table 1, we could determine the applicable media forms of the learning trail concept. Table 3 shows the outcome of this analysis, indicating with ✓ the conditions that applied and with ✗ those that failed. Unmarked entries do not contribute to the respective media form (cf. Figure 2).

Note that not all values of the Engagement Profile are equally important, and considerations on the impact on each value need to be made. For instance, the impact of E is considered to be weak in the case of the interactive media form, as time constraints apply for school classes (i.e., the duration of the visit is limited).

From Table 3 we conclude that the narrative and the communicative media forms apply for the learning trails in their generic formation. However, when a learning trail is performed by a single student, the communicative media form does obviously not apply. As a consequence, the concept of the learning trails supports predominantly the activities of attending, apprehending, discussing, and debating. Note that the concept of the learning trails does not focus on debating as an activity. Elements of investigaging, exploring, and experimenting are present, but not predominantly. The activities of practising, articulating, and expressing are least present, and we recognise that the learning trails are not developed for these activities.

6. Studying the Learning Trails

We wanted to explore whether we can observe differences for the operation modes *I* and *II*, as well as other characteristics of the learning trails. We studied this by collecting data from school classes performing the learning trail and analysed these data by aligning them with observations.

6.1. Test setup.

Each of the three learning trails consisted of three experiments, here denoted as A_t, B_t, and C_t for learning trail t. After each performed experiment, the participants answered a micro survey M with four questions; after the last micro-survey there was one further question denoted as survey S. See Table 4 for the survey questions. Finally, all participants answered a Kahoot quiz K where the correctness of the students' answers were evaluated. Thus, each group undergoes one of the sequences $A_t MB_t MC_t MSK$, $B_t MC_t MA_t MSK$, or $C_t MA_t MB_t MSK$. The answers given in the micro-surveys and the positioning data were stored in the respective tablet PCs and analysed later.

We implemented this entire procedure for both modes, that is Mode *I* for the paper-based version and Mode *II* where interactive content is pushed to the students' devices when approaching the respective experiment. In our study, the participants were divided into groups of three or four; one participant was pointed out as the leader of the group. All group leaders received a tablet PC that was

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Table 4. Formulation of the questions and scales for experiment i and learning trail t. The second column indicates the category (F=fun, R=recommend, A=use again, K=knowledge).

M_{1it}	F	How much did you like Experiment (i,t)? — scale: 1-7 (not at all – very much)
M_{2it}	R	I recommend Experiment (i,t) to others who visit the science centre. — scale: 1-7 (totally disagree – totally agree)
M_{3it}	A	When I'll visit the science centre next time, I'll use Experiment (i,t). — scale: 1-7 (totally disagree – totally agree)
M_{4it}	K	How much did you know from your school classes about the subject of Experiment (i,t). — scale: 1-5 (1=nothing, 2=a little, but don't remember much, 3=something, 4=quite a lot, 5=very much)
L		Which of the experiments A_t, B_t, C_t did you like best?

used for answering the micro-surveys, for logging the relative position of the device, and for accessing the content (mode *II* only). Participants that were not group leaders could answer survey questions on tablet PCs that were placed near the installations they visited. The participants were not aware of the test setup of other groups.

As each session included up to nine groups of students with three to four participants each, we made some precautions that groups do not interfere with each other, e.g., use the same installation concurrently.

We developed separate apps for each of both modes: App I for the paper-based version implemented the micro-surveys and logged the relative positions to the beacons. The micro-surveys were automatically triggered when a group left an area or time was up. This version did not give access to extra content. App II automatically presented tailored content when the participants approached an experiment; it also implemented the micro-surveys and logs. Note that all participating groups were given a tablet PC under the trials to avoid an extra bias when some groups used a tablet PC while others would not.

The questions of the micro-surveys given in Table 4 reflected whether the participants liked an experiment, recommendation to others, the willingness to use the experiment again, and which of the three experiments they liked best. These factors can give a good indication whether a participant liked an experiment [27]. Additionally, a self-report about the pre-visit knowledge can indicate how much they learnt, together with the number of right and wrong answers in the quiz.

We had planned a further question whether the participants had enough time to use the installation. However, after preliminary tests, we recognised that the learning trails were absolved much faster than anticipated. Consequently, this question was obsolete and removed from the survey.

6.2. Test Results

Students from school classes at the lower secondary school in the Oslo area participated in the study. In total, five sessions were done between Autumn 2016 and Spring 2017. In total, $113(34, 38, 41)$ participants appear in our log files; the numbers in parenthesis denoting participants in the learning trails "Forces", "Sound", and "Light", respectively. The students were divided into groups of two to four to enable discussion and interaction in between them. One of each group was selected as spokesperson, here denoted as the group leader. The number of group leaders was $n = 41(14, 14, 13)$; $n = 14(5, 5, 4)$ for Mode *I* and $n = 26(9, 9, 8)$ for Mode *II*. The number of samples was too low to determine whether Mode *I* or Mode *II* was more engaging; we did not recognise obvious trends.

6.2.1. Results for all participants

Figure 6 shows the results from the questionnaires for the variables F, R, and A for each of the nine experiments and for all participants. As expected, the installations in the learning trails received different ratings. This result can be used by the science centre to evaluate which of the experiments are liked better than other experiments. As an observation, it seems that the leaning trail for light received a lower rating than the two other ones. Further, the experiment *centrifugal governor* received lower

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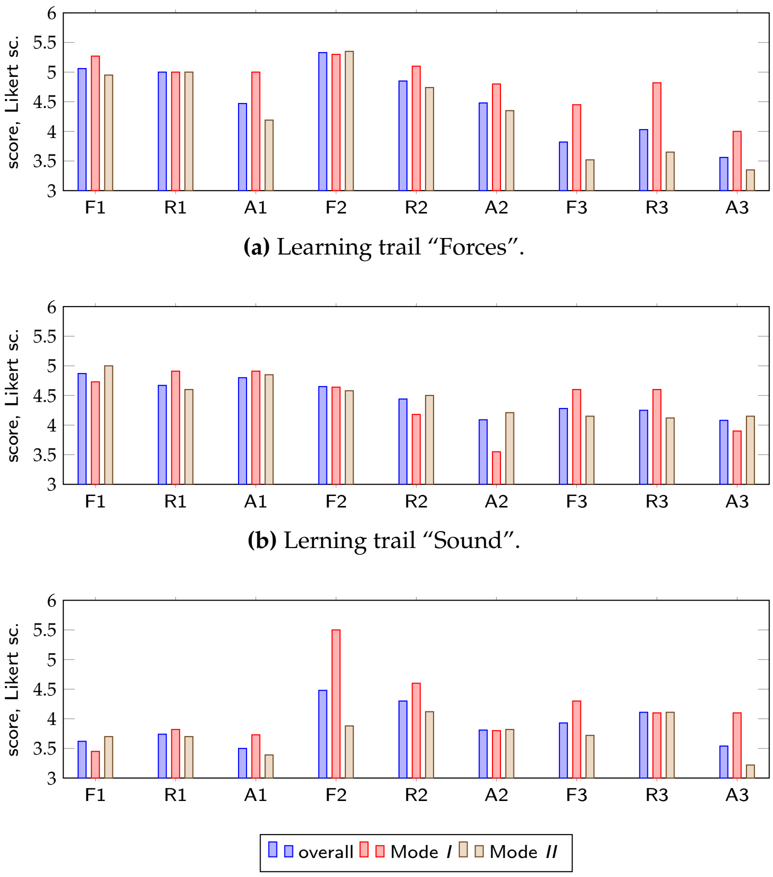

(a) Learning trail "Forces".

(b) Lerning trail "Sound".

(c) Learning trail "Light".

Figure 6. Response scores for tests with three learning trails and the three stations i on a Likert scale for the variables for *fun* F_i, *recommend* R_i and *play again* A_i. The number of participants is $n = 113(34, 38, 41)$.

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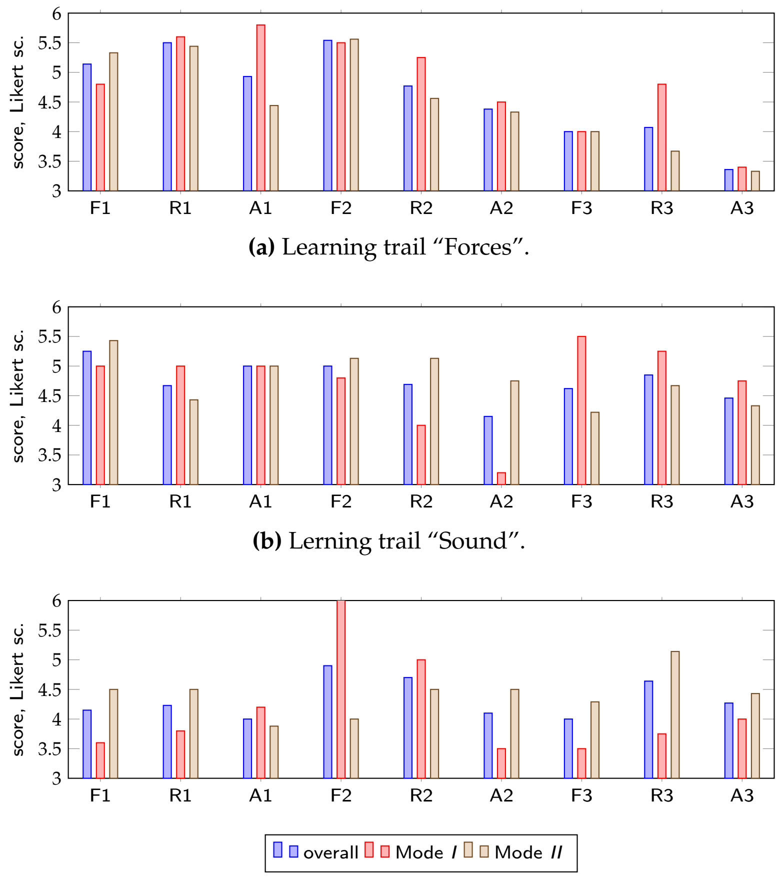

(a) Learning trail "Forces".

(b) Lerning trail "Sound".

(c) Learning trail "Light".

Figure 7. Group leader response scores for tests with three learning trails and the three stations i on a Likert scale for the variables for *fun* F_i, *recommend* R_i and *play again* A_i. The number of group leaders is $n = 41(14, 14, 13)$; $n = 14(5, 5, 4)$ for Mode *I* and $n = 26(9, 9, 8)$ for Mode *II*.

Table 5. Number of group leaders who liked which experiment best.

Experiment	#1	#2	#3	no vote
"Forces"	9	4	0	1
"Sound"	3	5	5	1
"Light"	4	0	6	3

rating than most of the others. We observed some unexpectedly high values for the learning trail for light in one of the experiments for Mode *I*.

6.2.2. Results for group leaders

As we suspected irregularities in the data set caused by the technical setup of stationary tablet PCs used for the micro surveys, we also extracted the data for the group leaders. The results for group leaders are shown in Figure 7. Still, it is not obvious which of the two modes was more engaging.

6.2.3. Group leaders vs. ordinary participants

We classified the answers into those from group leaders and ordinary participants for Mode *I* and Mode *II*. From these results, shown in Figure 8, we did not recognise significant differences in pre-visit knowledge between the participants. For the variables F, R, and A, we cannot see significant differences between the four groups. However, the participants in Mode *II* give slightly lower scores for all three variables.

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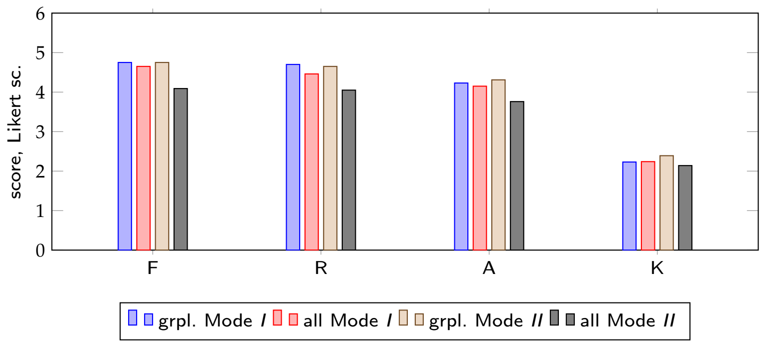

Figure 8. Response scores for tests with learning paths on a Likert scale for the variables for *fun* F, *recommend* R and *play again* A and pre-visit knowledge K.

Table 6. Results from the knowledge questions for all participants: percentage of right answers for all participants. Questions that are not related to the experiment are marked with $*$.

Question	"Forces"	"Sound"	"Light"
#1	73%	69%	44%
#2	21%	21%	19%
#3	24%	72%	14%
#4	9%	$*$ 13%	11%
#5	65%	$*$ 71%	50%
#6	$*$ 3%	14%	88%
#7	21%	56%	0%
#8	12%	15%	42%
#9	$*$ 56%	78%	54%
	32%	45%	36%

6.2.4. Experiment Preferences

The results for the question which of the experiments the group leaders liked best is shown in Table 5. Note that some group leaders failed to register for this question. For "Forces" and "Sound", these numbers are compatible with the results in Figure 7. However, for "Light", there is a discrepancy, as experiment #2 received no likes while it was rated rather high in the scores. As a further observation, the experiment "Pirouette" (see Figure 3a) received the highest number of mentions.

6.2.5. Knowledge questions

We evaluated the number of correct answers to knowledge questions. Each question has four alternatives where one of these is correct. Of the questions, there is always one "odd" alternative; it does not seem that the participants chose these to a large degree. Table 6 shows the percentage of correct answers. We marked questions that are about content that has not been presented during the experiment with an asterisk ($*$).

For the knowledge question, it is not significant whether Mode *I* or Mode *II* is used, nor whether the participants are group leaders. As a further observation, the pre-visit knowledge is in the average rather low (see the factor K in Figure 8).

6.3. Discussion of the Results

We went into the study with the expectation that Mode *II* would be preferred by the participants and, thus, resulting in higher scores. So far, we did not find evidence for this. We recognised that the number of participants in the single parts of the study is too small to show significant preferences.

The low impact of the mode to the result might be caused by a rather large impact of the design, activities, and use of other modalities to convey the content. In other words, the learning trail might be experienced to be multi-modal so that introducing a further mode (such as Modes *I* and *II*) has only a

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minor impact. Another source of error might be the research setting that the students might not be used to. Further, in our study, the presented content did not fully use the extra possibilities for the push-medium.

As a note, there are other studies where the mode of presentation did not have the expected impact. For instance, Vogt *et al.* [28] reported from a study where social robots were used to tutor children in second language learning. They could not find the expected differences in the learning effect between modes that were different in their implementation (tablet only vs. use of a social robot, the latter with and without the use of gestures), although they performed a large scale study.

In our study, there is an indication that participants that are not group leaders in Mode *II* give lower ratings for the variables for fun, recommend, and play again. Possibly, these participants are not enough included when the group leader is working with the tablet PC. Although this effect is rather small, that might be an indication that all participants should be given a tablet PC while performing a learning trail.

There was an expectation that the students will be more quiet with organised tasks, and the learning outcome will increase. During the study, we could observe that the students were more quiet compared to ordinary science centre visits, although we did not perform concrete noise level measurements. We leave this for future work.

There are indications that the characteristics of the learning trails may contribute essentially to our result. The content of the learning trail for light received low scores, which can be explained by the content being closer to the curriculum, being built up more theoretically, and having less engaging video content than the other two learning trails. However, note that the learning outcome is not necessarily related to the scores, nor to the Engagement Profile.

As a further note, the low scores for the experiment *centrifugal governor* could be a result of this experiment consisting of looking of an object and solving a simple task. This is also visible in the chart of Figure 5a.c. In contrast, the experiment *cup* (see the chart in Figure 5a.b) seems to be more engaging, and will evoke more enjoyment, inspiration, creativity, activity, behaviour, and progression.

For NTM, the correctness level for the knowledge questions is in the usual range, compared to internal studies. Commonly, the pre-visit knowledge is rather low when the students arrive at the science centre. As the subjects treated by the learning trails are rather theoretical, we expected that only few students were able to answer correctly. For school classes, pre-visit knowledge can often be more relevant than the learning outcome from the experiments.

The Kahoot-quiz was performed right after the learning trails had been performed, and the learnt had not yet been internalised by the students. Thus, the Kahoot could act as an engaging repetition that would have helped in the internalising process of the learnt knowledge. A repetition of the Kahoot some weeks after the science centre visit could have given more evidence.

NTM had tried several location-based concepts before; these have not worked well. In contrast, the learning trails using location-based services worked well.

6.4. Evaluation with the Engagement Profile

The Engagement Profile supports design choices for improvements of installations [5], here applied to the experiments of learning trails. For experiments that did not score high, we can consider which dimensions of the Engagement Profile could be altered. In the context of the learning trails, the social dimension S is already high, and changing S for experiments could interfere with the idea of the learning trails. The factors A and E are considerably high for the generic learning trail. Thus, we regard mostly the other dimensions of the Engagement Profile when considering improvements.

In our study, #3 of "Forces", #2 of "Sound", and all of the experiments of "Light" received low scores. In Figure 5a.c, the Engagement Profile of this experiment shows rather low engagement factors for #3 of "Forces". In Figure 5b.b, the Engagement Profile of this experiment shows low engagement factors but E for #2 of "Sound". The same is valid for the experiments for "Light", as can be seen in

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Figure 5c. Thus, either of the factors but S (and to some degree A and E) can be considered for an improvement of these experiments.

From our previous work [3] we know that the factors C, P, and U are important for the target group (school children). To improve the experiments of the learning trails, we recommend adding more competition, adding more physical activity, and/or designing the experiments for more user control.

6.5. Learning Trails and the GLO

To answer which GLO are supported by the learning trails, we revisit the five outcomes. The media forms and learning experiences derived from the Engagement Profile (see Table 1) are used check which of the GLO is supported by the learning trail concept.

Knowledge and understanding: The activities of attending and apprehending are supported, while activities such as exploring or experimenting are more a part of the single experiment. Generally, the learning trails can be said to support this outcome.

Skills: The activities of practising, but also investigating, exploring, and experimenting are not predominant in the learning trails. Although these activities might be supported by the single experiment, the learning trails do not support this outcome in general.

Change of attitude: The concept of the learning trails is too generic to support this outcome. However, specific experiments in the learning trails might support this outcome.

Enjoyment, inspiration, and creativity: We found that the mean value of the responses for "I liked the experiment" were on the positive side for almost all single experiments. Unfortunately, we could not test the generic learning trail separately, as the single experiments would have had a significant impact on enjoyment. For inspiration and creativity, the single experiment will have most impact.

Activity, behaviour, and progression: Their outcomes are not measured with the learning trails. Further, as the productive activity is not supported by the generic learning trails, this cannot be said to be supported.

Thus, we conclude that for the concept of the learning trails, knowledge and understanding as well as enjoyment are the most predominant terms of the GLO.

7. Conclusion

The science centre NTM has developed the concept of learning trails where a number of thematically connected experiments are performed by a group of students. A learning trail can be implemented based on laminated sheets or using apps on a tablet PC and location-based online content. In our study, we could not find evidence which of these two modes is better liked or gives a better learning outcome. The learning trail "Forces" performed best in our study. Further we discussed the scores for the learning trails and single experiments from the findings of our study. In our study, the number of samples was too low, i.e., more experiments are required to evaluate which learning trail or experiment scores better than others.

We used the Engagement Profile as a roadmap for suggestions to improve the experiments of the learning trails in the study by considering those dimensions of the Engagement Profile that are low for the experiment and the overall learning trail. It is the task of designers to suggest the concrete changes that are needed to increase engagement.

We also developed an indicator to determine the media form of exhibits. The concept of the learning trails implements mostly the narrative and communicative form, supporting the activities of attending, apprehending, and discussing. We also related the Engagement Profile to the media forms and the GLO by setting up a set of condition for translation.

For NTM, the learning trail concept is promising and will be further developed to give students an engaging experience in the science centre. In the study performed with secondary school students, the

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overall rating for most of the experiments and for the concept were on the positive side, i.e., in average larger than 3.5 on the Likert scale. Further, the study also gave evidence which of the experiments were preferred. The Engagement Profile of the experiments can show how to adjust the experiments to increase the engagement factors (see also [5]). Our research could also show that the learning trails primarily support the GLO of knowledge, understanding and enjoyment.

Conflict of Interest Statement

The experiments were performed at the NTM, where two of the authors (J.A.A., H.H.) are affiliated. The learning trails were implemented as a potential product by Expology, where one of the authors (G.J.) is affiliated. Beyond these facts, the authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions

All authors contributed to this paper as joint work in the context of the VISITORENGAGEMENT project. W.L. and I.T. developed the concept, while W.L. prepared the scientific background. J.A.A. and H.H. developed the concept of the learning trails. G.J. and I.T. implemented the learning trails at the NTM and performed the experiments at the NTM together with J.A.A. and H.H. W.L. and I.T. analysed and discussed the data. The paper was written by W.L. with text contributions by all co-authors.

Photographs

The photographs in Figure 3 were taken by some of the authors during the study at NTM. The persons depicted on these images have given their written consent that photographs taken during the study can be used in publications.

Data Protection

The VISITORENGAGEMENT project is registered with the Norwegian Centre for Research Data (NSD) who acts as a data protection ombud for studies performed in the project. Personal data gathered during the study have been anonymised or deleted after analysis. We state that personal data of participants in the study cannot be retrieved from the here published results.

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Project Information

The objective for the VISITORENGAGEMENT project was to measure the degree of engagement and user experience in science centres and museums. This was done by means of sensor and camera technology and the registration of user behaviour, in combination with short surveys. Project partners were Expology, Norsk Regnesentral (Norwegian Computing Centre), The Norwegian Museum of Science and Technology, The Norwegian Maritime Museum, Engineerium, and the Department of Education at the University of Oslo. For information about the project, we refer to the project base entry at the Research Council of Norway [29] and previous publications [2,3,5,11,27,30].

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Abbreviations

The following abbreviations and names are used in this manuscript:

BLE	Bluethooth Low Energy
BYOD	Bring Your Own Device
EP	Engagement Profile
FM	Frequency Modulated
GLO	Generic Learning Outcomes
GPS	Global Positioning System
NSD	Norwegian Centre for Research Data (norw. Norsk Senter for Forskningsdata)
NTM	Norwegian Museum for Science and Technology (norw. Norsk Teknisk Museum)
PC	Personal Computer
RFID	Radio Frequency IDentification
TMSI	Temporary Mobile Subscriber Identity