Science Center To Go
A Mixed Reality Learning
Environment of Miniature Exhibits

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Abstract

Modern science museums deliver exhibits that involve visitors in sessions of active playful learning. Mixed Reality may additionally be used as a catalyst for science centre exhibits to provide new perspectives and reveal otherwise hidden phenomena. Such sophisticated exhibits might well be qualified for improved learning at school – except they are hardly available outside of science centres. Our approach addresses this challenge by bringing miniaturized Augmented Reality exhibits out of the science centre into schools. The presented miniature exhibits uncouple science centre exhibits from their traditional venue and deliver natural ways of learning whenever and wherever it is desired. Therefore a set of miniature exhibits has been designed with the ambitious goal to meet the requirements of nowadays school curriculums. In this paper a science centre in a suitcase will be presented and discussed offering tailor-made learning experiences augmented through normal computers.

Keywords

Augmented Reality, Mixed Reality, Learning, Tangible User Interface, Science Museums

1. Introduction

The main idea of modern science centres or science museums has already been expressed in the following old Chinese saying: "Tell me, and I will forget. Show me, and I will remember. Involve me, and I will understand". Usually a museums visitor is passively looking at museum exhibits advised not to touch any objects. In modern science centres, on the other hand, visitors become an active part of each exhibit and get involved into experimental learning sessions. Such an active involvement demands sophisticated exhibits which work on many levels. Each exhibit is especially designed providing a new perspective on a subject. This perspective is created through interaction with the exhibit and usually addresses multiple senses. In the EU-Project CONNECT such hands on science centre exhibits have been extended through Augmented Reality (AR) to virtually show phenomena which are hard to implement in real models.

The main idea of CONNECT was the integration of science centre visits into the school curriculum. Adaptability of learning content and remote participation are both key factors of CONNECT. On the one hand a science centre visit is time consuming and relatively

expensive for school classes. On the other hand, it is very challenging to integrate given exhibits into the curriculum. The CONNECT platform provides a solution for both of these challenges. The virtual AR content can easily be adapted to the school curriculum via a web interface, and an audio-video stream allows for distant participation of classmates. However, such a remote connection does not transport the full hands on experience of the real science centre – the accessibility of science centre learning is basically still limited to a live video broadcast. [1] [2]

In EXPLOAR, the follow up project of CONNECT, this platform has been evaluated in detail and its AR component has been revised. As part of the revision the problem of limited accessibility has been tackled by the development of a miniaturized version of one of the AR exhibits. First tests of this so called "Science Center To Go" seemed promising and lead to a new project called SCeTGo for further refinement and detailed evaluation. Within the SCeTGo project a suitcase full of miniature exhibits is being developed and evaluated. The project focuses on a direct integration into the school curriculum to further bridge the gap between science centres and learning in schools.

In the following, we will present the concept and first prototype of this system. After taking a look at related work in section 2, we will give a more detailed overview of our concept in section 3. In section 4 we describe the first set of miniatures of the Science Center To Go suitcase before we discuss our findings and future work in section 5.

2. Related Work

As previously mentioned, the Science Center To Go is based on work of several consecutive projects. Its basis has been set in CONNECT, which brought Augmented Reality into science

centres to create novel learning possibilities [2]. Rich mixed realities learning experiences were created by enhancing real exhibits with virtual content. A web platform enabled teachers to adapt learning content to the school curriculum and give access for distant learners [1].

In the project EXPLOAR the existing CONNECT system has been extended and the idea of the Science Center To Go was born to bring the full hands on learning experience outside the science centre. The first miniature exhibit called the MiniWing has been developed and went through first evaluations and iterations of refinement. While the CONNECT AR-component build on expensive sensors and highly sophisticated setups Science Center To Go aims for increased accessibility through optimized simplicity. A key aspect of the Science Center To Go is to target a broader audience and ideally hit a mass market, therefore only off the shelf hard and software is being used. [3]

CONNECT, EXPLOAR and SCeTGo are examples of AR based learning support with a high emphasis on physical interaction. On the other hand numerous AR based tools for learning have been developed and investigated, where less emphasis was put on the physical interaction model, e.g. the Spinnstube® [10] or the Protein Magic Book [11].

Tangible User Interfaces (TUI) were first introduced by Ishii & Ullmer [4]. They seek to integrate computing power into everyday live by connecting physical objects to computers. Virtual digital functionality is assigned to real physical objects in order to achieve a more intuitive and effective way of interaction. TUIs built on the advantages of multi-sensorical interaction.

Ullmer and Ishii [5] state that an interaction device has a digital and a physical representation. When the electric power of an interface is removed the digital representation

disappears and the physical representation remains. They further say, that "[t]angible interfaces are products of a careful balance between these two forms of representation." ([5], p. 3)

Science centres demand hands on playful learning. We are building on Tangible User Interfaces to deliver a broad experience and lower the burden for learning while improving usability.

Following constructivistic ideas Resnick et al. [6] introduced Digital Manipulatives, which put emphasis on learning with physical objects. The basic concept is the integration of computational and communications capabilities in traditional children's toys. Information technology is implemented into toys for playful and experimental learning. The idea mainly focused on extending toys in a way that they can be programmed. Therefore, programmable bricks, so called "crickets" where embedded into different kind of toys. These could be programmed, and even communicate with each other via infrared. As an example a common ball is equipped with a color LED, an accelerometer, and a programmable brick. The cricket could then be programmed to react on different ball movements detected by the accelerometer, and, thus mimic its "mood" by displaying it through a changing glow.

If we have a look at the entertainment and toy market, there are several popular products that invite children - and interested adults - into exploring science. Experimental kits like the ones produced by KOSMOS [7] have been on sale since the early 20th century. With these, children acquire a set of test-tubes, jars, petri dishes, liquids, acids and other chemical elements and can conduct their own experiments at home.

A similar approach is undertaken by Lego with their so-called Mindstorms [8]. These extend the normal Lego blocks by adding motors, cameras, sensors and even a mini computer to the mix. This computer can be programmed by the users and enables them to build a variety of different creations which typically resemble simple robots [9]. By using Lego Mindstorms children take first steps into programming. The usage of light or temperature sensors on the other hand enables them to learn about other traditional physics topics.

3. Concept Evolution

The concept behind the development of AR science centre exhibits started off fairly simple by extending existing exhibits visually. In the beginning the "magic" of AR was simply enough to create added value and enhance the experience. Over the past projects and evaluations this "magic" gave way to actual usage. The concept had to be refined iteratively to meet new upcoming requirements of miniature exhibits designed completely from scratch. The design of the required software and tangibles goes hand in hand and has to be considered thoroughly.

In contrast to many other AR-Learning environments Science Center To Go miniatures built on common hardware, without any sophisticated processors, in- or output devices. The minimal hardware requirements comprise a screen, webcam, and a pointing device. The only main interaction device should be the physical model of the miniature – the miniature as a TUI. AR is achieved by using the Magic Lense metaphor [12], where a rear camera image is shown on the screen superimposed by computer generated virtual content. If the camera is pointed towards the user one might also call it Magic Mirror [13].

By building on the Magic Lense metaphor and Tangible User Interfaces co-located cooperation is fostered since multiple users are able to look at the same screen and manipulate the miniature simultaneously.

When designing a miniature AR exhibit one should also be aware of the spectrum of possible exhibits. We are now able to distinguish three types of exhibits: traditional exhibits without AR, exhibits enriched through AR (Hybrid AR exhibits), and TUI based AR exhibits (Exclusive AR exhibits).

In most cases an exhibit in a science centre is a physical installation that facilitates a comprehensive learning experience by modelling a new perspective through interaction. Thus, the creation of such installations demands great deals of engineering, structural, and logical complexity.

An exhibit for learning about Bernoulli's effect, for example, could consist of a simple wind tunnel, a turbine, and a model of an airfoil. The airflow might be indicated through particulates of fine mist of liquid sprayed into the tunnel. The learner would be able to physically manipulate certain parts of this model and directly see the changes.

Augmented Reality technology might now be used to enrich the experience of a common exhibit even further, and feature phenomena which are impracticable to present with real models. Giving the example of the airfoil, an AR system could additionally visualize the lift force, different areas of air-pressure, or stresses exerted to body parts. Therefore, the computer system needs to track the position and orientation of the wing and the velocity of the stream created by the turbine. The tracking data is passed on to a computer simulation model which creates virtual output data, such as the lift force. The virtual output is after all presented to the user on the screen.

Taking the virtualization even further leads us to Exclusive AR exhibits. Such exhibits work completely without any real simulation. The physical representation only serves as a tangible input medium or a TUI. The rest of the simulation and the output is computer generated. Such a system offers highest flexibility in order to adapt learning content. It also reduces the physical complexity of the exhibit, and thus lowers the barrier for being massively produced. However, the key challenge hereby lies in preserving a comprehensive learning experience as it is provided by a real exhibit.

Taking the airfoil example; in comparison to the hybrid AR exhibit, one could even remove the turbine and particles of fine mist and use computer graphics to visualize the airflow. In this case, the mechanical complexity of the physical representation was reduced to a simple wing rotating around an axle, which itself does not give much room for experimenting and experiencing Bernoulli's characteristics. All simulation and feedback were computer generated, allowing users to experiment with the airfoil model and see how this changes the airflow and forces.

The biggest risk of virtualization is a loss of valuable feedback and interactivity. By removing the turbine, as described above, learners would not be able to feel actual forces resulting from wind attacking the wing. Hence, one should be aware of the advantages and disadvantages of those different types of AR exhibits and consider virtualization thoroughly case by case. The spectrum described above is depicted in Figure 1.

AR adds a whole new range to the spectrum of science museum exhibits. Starting from Hybrid AR Exhibits to Exclusive AR Exhibits, physical complexity is removed with increasing virtual complexity. Hereby, Hybrid AR Exhibits add new possibilities to interact with science exhibits, while Exclusive AR Exhibits also increase flexibility especially regarding learning content, reproducibility, and mobility. Thus, Exclusive AR Exhibits provide the basis for fully functional miniaturized exhibits which can be taken away.
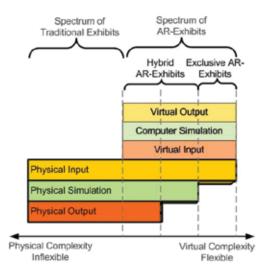
Figure 1. The spectrum of AR Exhibits

Finally one should keep in mind the fundamental qualities of a Science Center To Go exhibit which we determined in a previous paper [3]:

- Mobility: Miniaturizing exhibits by shifting simulation functionality into Mixed Reality

- Tangibility: Preserve the users' hands on experience

- Mass Producability: Increased virtuality enable simplified physical components to lower the barrier for mass production

- Accessibility: Miniaturized to pocket size; using common devices that are common in everyday life, such as regular PCs or smart-phones,

- Modularity: Follow the principle of modu-larity for extendable comprehensive exhib-its and to provide a shareable collaboration platform.

4. A science centre in a suitcase

The Science Center To Go software is based on the MORGAN AR/VR Framework and runs on typical desktop PCs and mobile computers

[14]. For tracking purposes we made use of the marker based ARToolkitPlus computer vision library [15], a further development of the original ARToolkit[16].

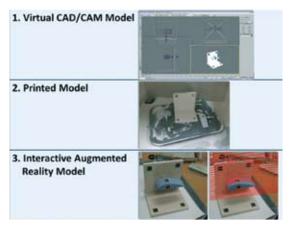The process chain of creating a miniature exhibit is visualized in Figure 2.

Figure 2. Three steps to a Science Center To Go exhibit

First a virtual base model of the exhibit is designed. In the next step a sufficiently accurate physical representation of this CAD model is being created. We use a Spectrum Z™510 3D printer providing us with an accuracy of a tenth of a millimetre. All further virtual information is then added in reference to the virtual base model. Fiducial markers serve as tracking points to precisely register the physical representation model and superimpose the physical miniature exhibit with virtual content.

After the MiniWing miniature proofed to be valuable, we now create new exhibits to comprehensively test and improve the Science Center To Go approach. The design of new exhibits follows the basic requirements of mobility, tangibility, mass producability, accessibility, and modularity, as it is detailed in [3]. Moreover, they are created in close cooperation with teachers and educational scientists to better meet the school curriculum. A typical setup of the current version of the Science Center To Go is shown below in Figure 3.

Figure 3. *Typical Science Center To Go setup: from right to left a suit case holding all exhibit parts, a laptop, and the playground for experimenting*

The suitcase stores all necessary elements for the existing five exhibits. Also included in the suitcase is a laptop with a touch screen, a webcam and a little stand. The webcam is placed on the stand and connected to the computer. On startup the computer directly opens the main screen where each experiment is represented by an image. Each image displays the corresponding experiment in action, also serving as guidance for users to correctly setup and use the system. After setting up the desired exhibit in front of the webcam a simple touch on the according image starts the software. The webcam stream is displayed on the computer screen and augmented with additional content. In the following we will describe the five exhibits currently included in the suitcase.

4.1 The Mini Wing Experiment

The MiniWing consists of a small box that stores the model of an airplane wing. The wing is about 5.5cm long, 3cm wide and 1.5cm high. It is connected to an axle that fits into a hole of the box (as seen in Figure 4). After the wing is brought into position, the user can easily rotate it and try out all possible angles of attack.

Only two markers are necessary for the Mini Wing: one is attached at the top of the box while the other one is placed directly on the wing. When the user rotates the wing, the software determines the current angle of the

wing by analyzing the tracking values of both markers.

The virtual representation shows the way the air flows around the wing according the angle of attack. Animated arrows visualize the different speeds of air, lift, and drag of the wing.
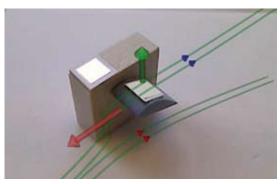

Figure 4. *the Mini Wing exhibit augmented through the airflow. Two arrows are displaying the lift and drag*

This way the user is able to learn firsthand about the Bernoulli Effect. By experimenting and interpreting the results, they learn that the best angle of this wing for optimal lift of the plane lies between 15 to 20 degrees.

In further iterations differently shaped wings will be added. Also a fan will be integrated to control the air stream.

4.2 The Doppler Experiment

The Doppler Experiment consists of a fire truck and a virtual microphone representing a sound recording device or listener. The fire truck is stored in the same box with the wing. The user should open the box and put its lid in front of the camera - a virtual microphone appears at the marker of the lid.

The fire truck also holds a marker on its roof top. As soon as the truck is visible to the camera, sound waves are displayed and the sound of a fire truck siren goes off. The sound propagation is animated in a sequence of wave fronts that start off from the trucks siren and expand concentrically away from

the truck. The waves are emitted in a constant frequency. When the user moves the truck he moves the source of the sound waves causing the wave fronts to be shifted closer together in the direction the car is moving; the wave fronts are shifted further apart in opposite direction (compare Figure 5). At the same time the pitch of the siren audio is increased when the truck is moved towards the microphone and decreased when the truck is moved away. The pitch of the siren also changes when the user moves the microphone.
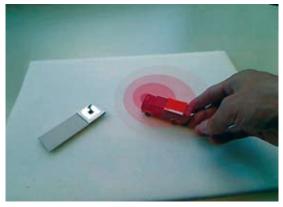

Figure 5. Sound waves of a fire truck displayed at the Doppler exhibit.

By moving fire truck or microphone the user gets an audio-visual feedback representing sound waves. This way users get a chance to learn about the Doppler Effect and the importance of relative difference in velocity between listener and the source. Observations made at this exhibit might easily be transferred to other physical phenomena related to the propagation of waves.

In further iterations different vehicles will be added providing a variety of sounds. Scenarios will be worked out to learn about the sonic barrier and frequency shift of moving light sources.

4.3 The Double Slit Experiment

The initial version of the double slit exhibit consists of the Mini Wing's box, a floor board and a screen with either a single or a double slit (see Figure 6). The box serves as the end projection plane. The selected slit screen should be fixated on the floor board so that it faces the projection plane on the box.

The slit screens and the box are registered via markers. The floor plane works as a fixation to ensure proper alignment and the right distances among all pieces.

Users are invited to test this setup with a virtual particle cannon or a wave field. In particle mode a virtual cannon appears at one end and starts firing virtual little "cannon balls" at the slit screen. Some of the balls are deflected while some pass the slit. The box projection plane is not deflective. When a ball passes through a slit towards the box it sticks to the box as soon as it hits it. After numerous balls a pattern analogous to the slit screen appears at the projection plane.

Figure 6. The double slit setup consisting of a floor board (dark), the slit board in the foreground, a box as a projection plane, and a virtual cannon

Users might be surprised when they test the same setup with waves. In this mode the cannon is replaced by a source sequentially emitting waves with a certain frequency. Wave fronts are spreading concentrically from the source. When a wave front hits a slit on one side a new concentric wave front goes off on the other side of the slit. The projection plane at the box finally shows the resulting interference pattern. For a single slit this results into a bright

band in the middle of the box. Is the single slit replaced by a double slit the projection turns into several bright bands of light as shown in Figure 7.
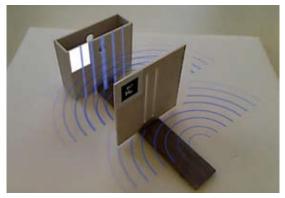

Figure 7. The double slit experiment show¬casing a wave field.

The waves are visualized and animated allowing ambitioned observers to search for areas of constructive and destructive interference.

By experimenting with the double slit exhibit users learn about wave propagation, interference, the particle wave duality of light, and quantum particles opposed to normal particles.

The current version is an initial prototype which obviously lacks some fundamental interactivity. In its next iteration learners will have more possibilities to change important parameters. They will be able to change the double slit distances, the distance between the slit screen and the projection plane, as well as the frequency of the wave emitting source.

4.4 The Double Cone Experiment

The double cone miniature consists of two rails of 12cm length each. The rails are jointly connected on one side; on the other side each rail rests on a ramp. The ramps provide an inclination of 1.5cm by 3cm. Additionally four rolling objects are available to be put on the rails. Three of the rollers are double cones and one is a cylinder. The opening angle measured

alongside the double cones differs between 15, 30 and 45 degrees.

As shown in Figure 8 the rails are resting on ramps on one side. If the cylinder is put on the construction it will role down the slope. However, when a double cone is set on the rails it might as well role the opposite way, up the hill.
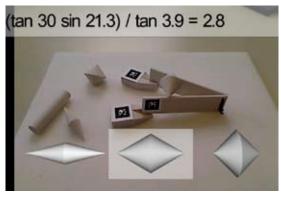

Figure 8. The double cone exhibit consisting of two rails, two ramps and four roller objects. The double cone selection interface buttons are shown in the bottom the resulting formula is displayed at the top of the screen

Three angles are important to understand and predict the behaviour of the double cones. One is the opening angle of the double cone roller (α), the other is the opening angle of the rails (β), and the third one is their inclination (χ). The angle referring to the double cones shape is selected via the user interface. Three markers are used to precisely capture the remaining angles. The opening angle is calculated from the two markers on the ramps and the resulting distance between both ends of the rails. The slope could have been determined directly from the orientation of the marker attached to the rail. Though, for increased precision the marker on the adjacent ramp is used to determine the position of the rail alongside on the ramp which gives us the lift of the rails ends. From here we are able to precisely deduce the inclination.

The relation of all three relevant angles may be

described by the following expression:

$$\frac{\tan \alpha * \sin(\frac{\beta}{2})}{\tan \chi} \quad \text{(I)}$$

If the result of this expression is greater than 1 the selected double cone should role towards the ramps otherwise it roles in opposite direction. The setup allows learners to easily change all relevant angles. The opening angle of the ramps is changed by moving the ramps apart. The incline is changed by pushing the rails up or pulling them down the ramps. The roller object has to be selected using the on screen buttons for each double cone. The formula for predicting the behaviour of the experiment is shown and instantly updated at the top area of the AR-screen.

This exhibit directly estimates the prediction model described by a mathematical expression and a real experiment. Hereby learners should be able to learn about the physical logic underlying the double cone experiment. Those experiments might also reveal typical misconceptions related to gravity.

In a next iteration it is planned to highlight the relevant angles on the camera image.

4.5 The Boltzmann Experiment

The Boltzmann experiment contains three objects: A refrigerator, a heating surface, and a thermometer. Since touch is important for hands on learning the refrigerator actually gets cold and the heating surface heats up. The exhibit also includes a functioning infrared thermometer, which displays the real temperatures of all objects.

Each object is registered through a marker. The markers of the fridge and the heating surface are used to determine the areas of high and low energy. The energy level between those two extremes is smoothly interpolated to provide a realistic transition.

After setting up the experiment users are able measure the temperature with the thermometer at different areas of their setup. Additionally, molecule movement is visualized at the top of the thermometer (see Figure 9). On the AR screen users might observe that molecules in areas of a high energy, near the heating surface, move faster than molecules around areas of low energy, e.g. inside the refrigerator.

With this experiment learners should get a deeper understanding and insight into the relation between energy, temperature and molecule movement. In a next version a graph will be added showing the Boltzmann distribution.
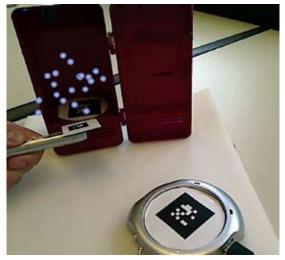

Figure 9. The Boltzmann exhibit: Heating plate in the front refrigerator in the back. The user holds the thermometer into an area of low energy and recognizes a slower movement of the molecules.

5. Evaluation, Discussion and Future Work

The five exhibits described above where consecutively developed. While the Mini Wing went already through 3 iterations newer exhibits are in their initial generation. The Mini Wing and the Doppler have been tested most extensively. Results of these tests and related evaluations are described in [17].

The Mini Wing has also been presented at multiple venues. The feedback in general was quite positive while critical feedback usually was constructive. One child testing the Mini Wing, for example, asked why it would not feel any wind blowing at the wing when it could see an air stream on the computer screen. So we bought a USB powered fan to be prepared for this question next time. After testing the fan we found that the actual air stream created a much richer experience. We underestimated the sense of touch, and did not add a real air stream although we were trying to develop science centre like exhibits. The critical comment of the child made us reconsider the Mini Wing in respect to the spectrum of AR-exhibits as described in section 3.

For the development of miniature exhibits we deduced that one should first determine all senses activated by the real experience. As soon as a sense is not addressed due to virtualization, there is a good chance that certain expectations are not met and the whole experience does not "feel right" for the learner. Realism might be important for the learning effect, since the output created by the AR-component should be believable in order to be believed. The following interesting questions arise from this observation: Do realistic miniatures achieve better learning effects than others? Does, for example, a real air stream improve learning because it makes the virtual AR information more believable? Taking this further leads to a more fundamental question in learning in general: Do we learn better on abstract or concrete content? These questions seem to be relevant for any future work and need to be addressed.

Other feedback we received by an expert was concerning the size of the exhibit. Does a miniature exhibit achieve the same learning effect as its big replication? It is important to extract characteristics that change when an exhibits is being miniaturized and to find out how they influence the learning experience. Some of the miniature exhibits portrayed above are already available in different sizes. The Mini Wing for example is a scaled down copy of an exhibit created for the first project CONNECT; the original wing is ten times as big as the miniature wing. Just as well the double slit is available in a version which is approximately three times bigger than the one in the suitcase.

The exhibits will also be systematically evaluated and refined. There is still plenty of room for improvements in all relevant areas. First of all, concrete guidelines on the design of miniatures are inevitable. Some general answers and guidelines are still missing, such as when should the virtual content exactly match reality and when should it be metaphorically modified. Obviously, we also need to develop and test further exhibits to cover a wider range of topics. Before we create new exhibits, we first will have to improve modularity of the existing pieces.

Since the miniatures serve as Tangible User Interfaces for the AR system there also needs to be done some more testing on human computer interaction especially with miniature exhibits. In respect to this the whole AR component might be revised and updated where necessary.

Technically it might be helpful to integrate an alternative computer vision tracking based on natural features. The cause why natural feature tracking has not yet been integrated has two main reasons: first it demands more computing power, and second it is hard to place many features on small surfaces, as it would be necessary for miniature exhibits. Natural feature tracking, however, could probably be integrated after a proper redesign of the exhibits. The other alternative is edge based object tracking. This variant seems to be even more promising, since we already have accurate real representations of our virtual

models. Both tracking approaches need to be kept in mind for further updates of the AR component.

Since mobility is a key factor for Science Center To Go exhibits, we should also follow recent trends and move the system to mobile handheld devices. Currently we focus on common tablet computers or laptops as end user devices. A shift to mobile devices and smart phones would also increase accessibility and broaden the audience.

Finally and most importantly the miniature exhibits have to be evaluated thoroughly to analyse the learning effect. With its major target group of pupils at schools it has to be integrated into the school curriculum. Both aspects will be approached in the coming evaluation phases of the SCeTGo project.

We are still confident that the Science Center To Go idea is a valid approach with very high potential for success. With further work and research similar miniature exhibits might soon find their way into every day learning.

6. Acknowledgement

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