Guide of Good Practice

Science Center To Go

Design by Ellinogermaniki Agogi

| Guide of Good Practice |

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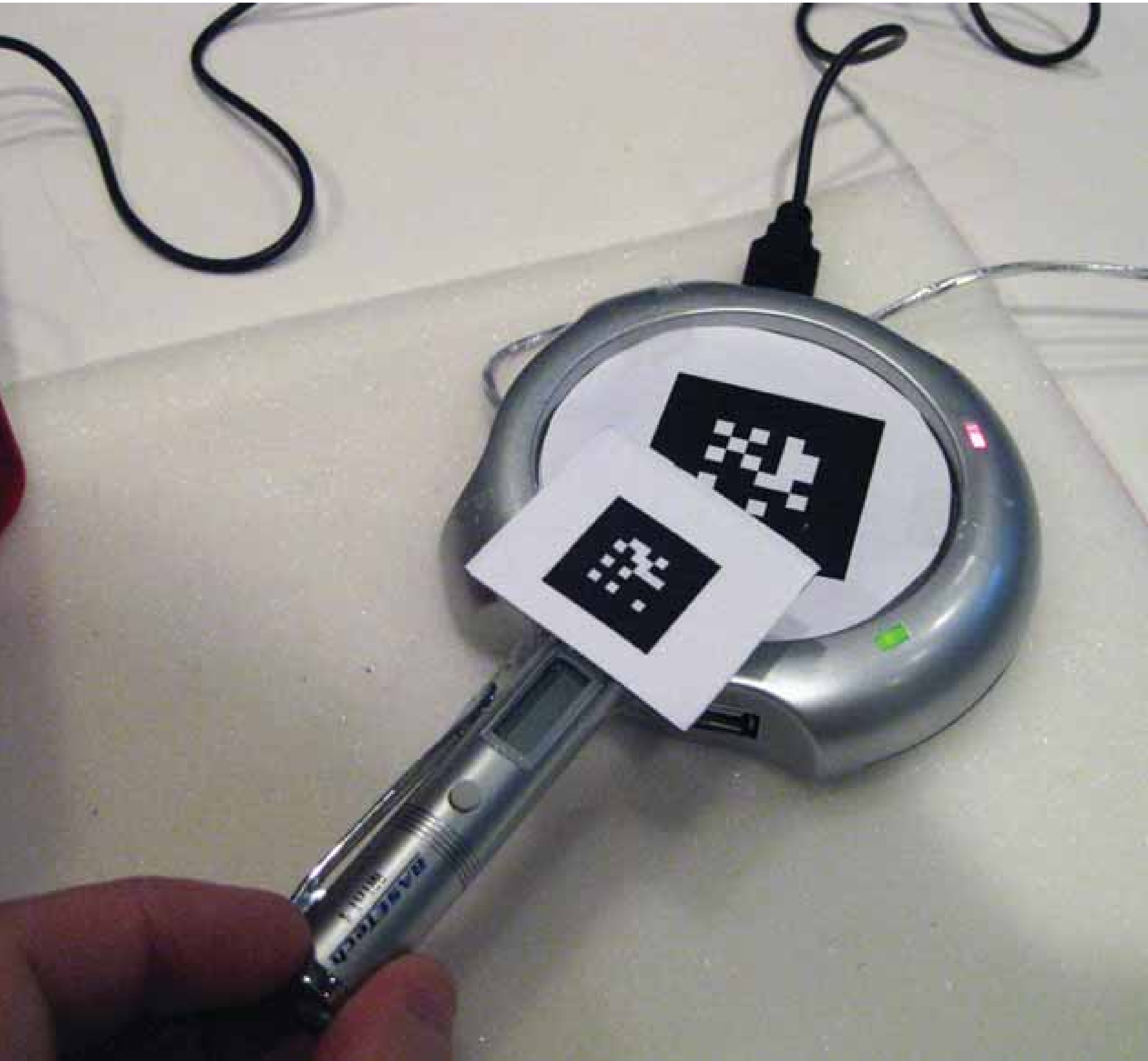

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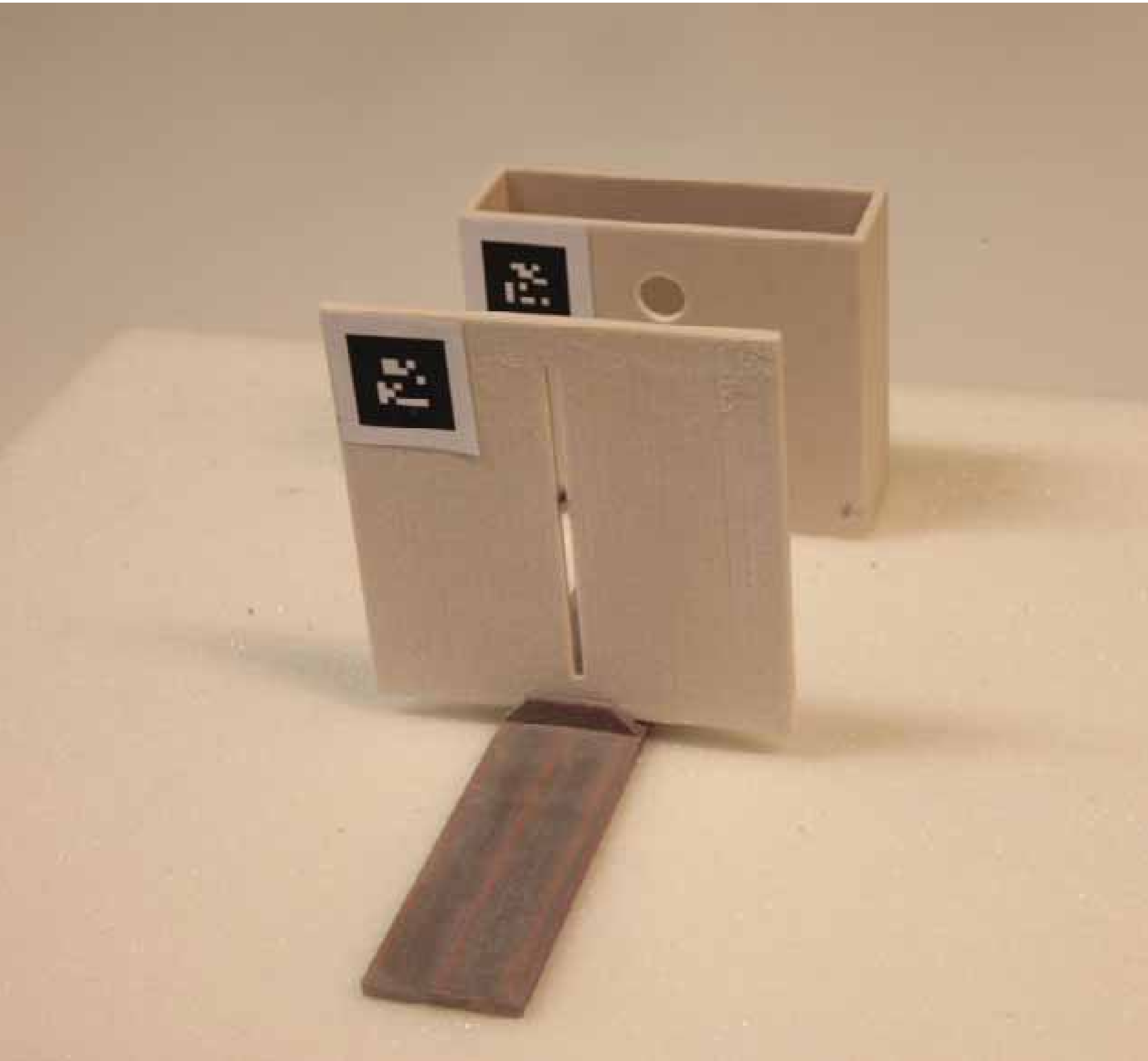

1. Introduction

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1.1 Introduction

There is sufficient evidence to suggest that both the persistence and the quality of learning are highly enhanced when the potential learner is actively participating in the learning process [1, 2]. Science Centers (SC) adopt this philosophy by offering intriguing exhibits that enable their visitors to experience science first hand by actively manipulating the experiments, thus delivering natural ways of active playful learning. Modern technologies like Augmented Reality (AR) are often used to enrich the experience and display otherwise hidden phenomena. However, experiencing augmented reality requires visiting the Science Center.

The Science Center To Go (SCeTGo) approach goes one step further and aims to bring similar comprehensive learning experiences out of the Science Center into a school's classroom and/or everyone's home. Its miniature exhibits - by "fitting into a pocket" and operating with ordinary hardware - enable learners to experiment whenever and wherever they please. This way the consortium makes full use of the powerful capabilities offered by tailor-made exhibits combined with AR.

1.2 The SCeTGo approach

The SCeTGo project aims to bridge the gap between formal & informal education, to promote science learning at all levels, and to assist in ensuring that science not only holds a high place in teaching curricula but also promotes creative problem solving and learning-by-doing. The overall objective, through the exploitation of AR, is to integrate experiential learning & supporting materials provided by scientists & educators into a comprehensive knowledge base for learning open to the public.

Figure 1.1 The Science Center To Go suitcase and contents (laptop not shown)

SCeTGo's approach is based on an educational kit that is delivered in the form of a small suitcase (Figure 1.1) and contains a tablet, a web camera, a series of 3-D printed miniatures and a user guide. These miniatures combined in various arrangements can form in total five mini- exhibits that illustrate various physical phenomena linked to secondary school curricula: sound wave propagation, rigid body (double cone) motion on an inclined plane, wing dynamics, wave-particle duality and gas particles' velocity distribution. Learners can interact dynamically with the miniature exhibits and by using AR enrich their optical view with information relevant to the physical phenomena shown. Examples of the physical phenomena include explanation of why do planes fly and why does the siren sound of a fire truck is different when it approaches an observer than when it moves away from him.

In the framework of the project the SCeTGo partnership has developed, implemented and evaluated a series of learning activities in accordance with the current trends in science education, based on inquiry and problem based approaches that allow the actively participating learners to enhance their scientific literacy and critical thinking skills. Educational scenarios following the inquiry-based teaching methodology have been designed for all miniature exhibits. These scenarios by making use of AR introduce new ways of interaction between learners & the real world.

In general, SCeTGo demonstrates to learners through the merging of the miniature exhibits and the AR technology new ways of interacting with scientific concepts and phenomena. A detailed description of all five SCeTGo exhibits, shown in Figure 1.2, enriched by images and videos can be found at the project's official website [3].

A snapshot of this website is shown in Figure 1.2.

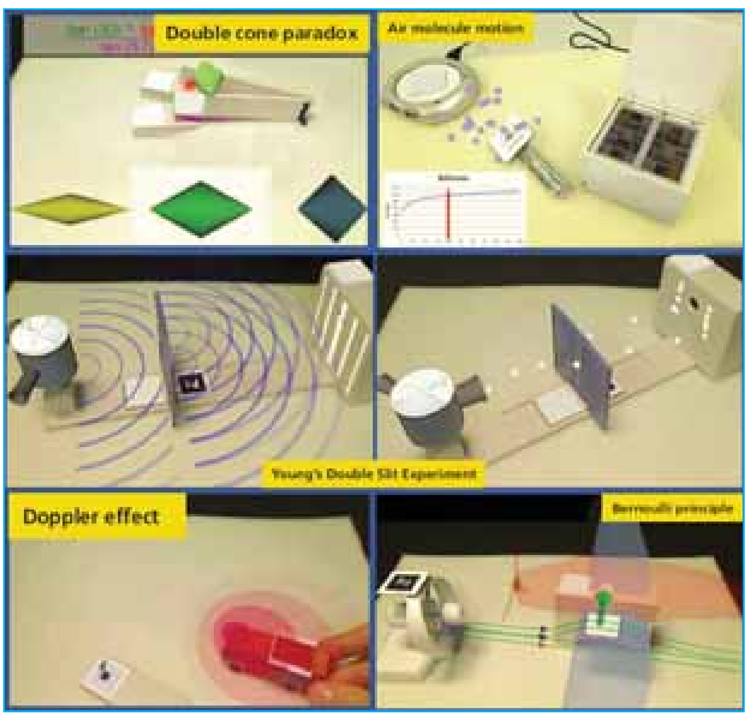


Figure 1.2. The five SCeTGo miniature exhibits

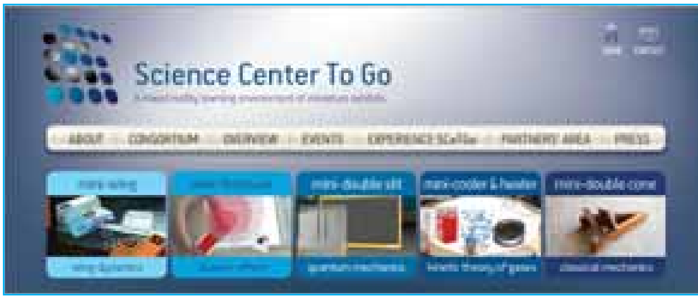


Figure 1.3. *The SCeTGo website: www.sctg.eu*

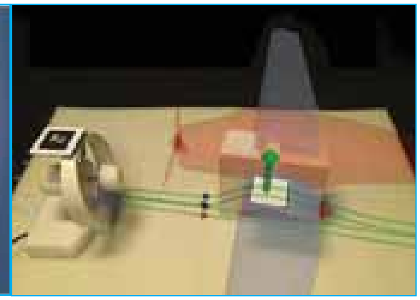


Figure 1.4. *The mini-wing as it appears on the laptop's screen*

1.3 Innovative Characteristics

The SCeTGo project introduces an ICT-enabled learning approach that has the following innovative characteristics:

a) Makes use of advanced visualization technologies (AR) that not only have the potential to enrich the learners' optical view with relevant information but also allow the learners to interact dynamically with the miniature exhibits

b) Is easy to operate. As it is based on common devices there are no real obstacles that a potential learner has to overcome in order to use the system.

c) Promotes an inquiry-based and experiential learning approach. Learners experience science first hand at their own leisure and engage in activities where information is discovered by them rather than passively transmitted to them. By interacting with the miniature exhibits learners can not only visualize invisible physical quantities but can also control the conditions that need to be met in order for a phenomenon to occur (e.g. learners by rotating a miniature wing, namely the mini-wing exhibit shown in Figure 3, at different angles can see through the airflow augmentation on the wing, why planes fly)

d) Demonstrates the possibilities that students will experience in the future during their educational training in respect to AR technological applications.

e) Promotes the importance of science to all European citizens through a journey of entertainment & learning.

f) Contributes to the development of a new generation of citizens who are scientifically literate and thus better prepared to function in a world that is increasingly influenced by science & technology

g) Offers a modern science centre experience outside the walls of the science centre in school classrooms.

1.4 Impact in Education & Society

The SCeTGo miniature exhibits illustrate various physical phenomena enabling learners to visualize the invisible through AR technology. Thus, they offer to science teachers the opportunity to introduce new approaches in the classroom by using the new customized AR tools and to students the opportunity to use innovative technology in the framework of their normal school curriculum. Moreover the SCeTGo project contributes to the access to and sharing of advanced learning resources not only between schools but also among science centres and universities. In this way it supports the provision of key skills to the future citizens & scientists (collaborative work, creativity, adaptability, intercultural communication).

On the other hand the SCeTGo approach facilitates lifelong learning as it aims to improve quality of learning by providing access to resources (mixed reality tools) with significant educational value and to reinforce the contribution of lifelong learning to social cohesion, active citizenship, intercultural dialogue, gender equality and personal fulfilment. These are major priorities of the EC's Lifelong Learning Programme which support the development of innovative ICT-based content, services, pedagogies and practice for lifelong learning. Furthermore, the SCeTGo approach helps learners to develop critical capacity and deeper understanding of the concepts underlying scientific investigation. In this framework, the objective of SCeTGo is not solely to produce more scientists and technologists; it is also to produce a new generation of citizens who are scientifically and technologically literate.

Finally, SCeTGo project is aiming at promoting population's interest in science by building on the strengths of both formal educational settings (e.g. secondary schools) and informal learning environments (e.g. homes, science centers and science museums).

1.5 Implementation & Dissemination Events

Over the last two years (2010 & 2011) the SCeTGo approach was either implemented (through workshops, trials etc.) or disseminated (through conferences, seminars etc.) in 126 different type of events in more than 12 countries around Europe. The total number of events along with its type per country is shown in Chart 1.1.

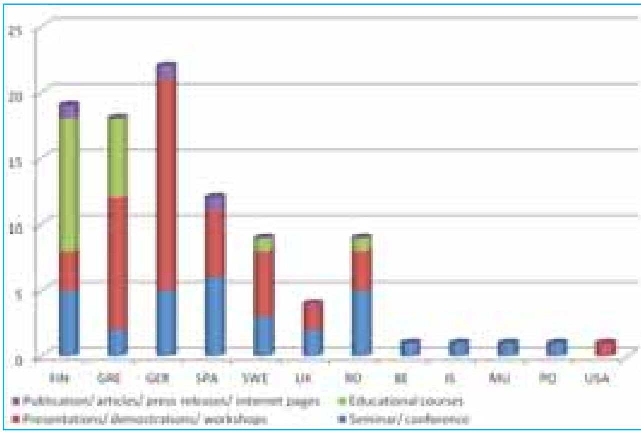


Chart 1.1. *All events by country*

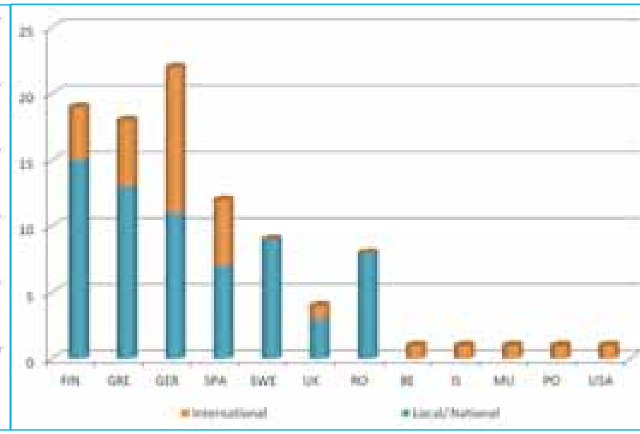
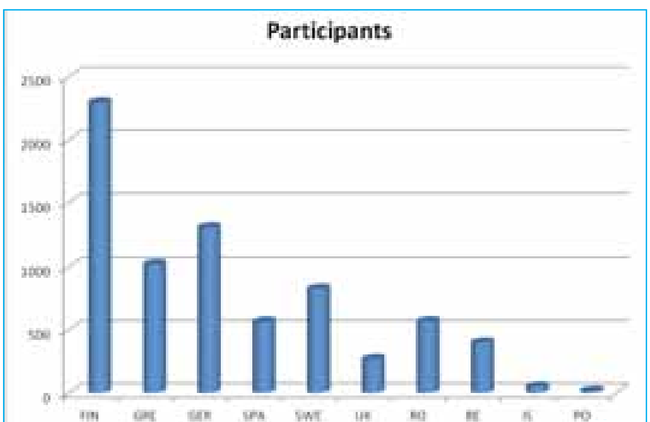


***Chart 1.2**. Internal or local/national events by country*

Most of the events were organised in SCeTGo partner's countries but there were also major events that took place elsewhere e.g. in Scientix Conference in Brussels, ECSITE meeting in Warsaw, Inventorium Education Symposium in Dublin and Nordic Science Center Foundation annual meeting in Reykjavik. In total SCeTGo was presented in 77 different seminars/ conferences and workshops, 18 educational courses, 3 publications, 12 articles and press releases and an internet page. Almost 70 of these events were local and national in partner countries and 31 international as illustrated in Chart 1.2. The total number of students, teachers, researchers and science center staff that participated in the above events and were informed about the SCeTGo project were 7300 as shown in Chart 1.3.



1.3. *Participants by country*

In Germany a newspaper article was printed 76906 times, FIT web pages were visited 900 times. In Sweden a magazine with an article dedicated to SCeTGo was distributed to 30.000 readers while a newspaper article was published with potential readers of 50000. University of Barcelona web pages were visited 939 times. The project's web page (http://www.sctg.eu/) was visited 2135 times during the project life-cycle. TOP 10 countries were our project web page was visit were Germany 355, Finland 333, Greece 328, Sweden 203, Spain 124, Romania 110, Brazil 85, United States 82, UK 79 and Belgium with 41 visitors. The results were taken from Google Analytics.

Validation and demonstration of the SCeTGo –system have been implemented in several other occasions such us workshops, exhibitions and conferences all over Europe. These activities were carefully planned from the day one of the project and have been implemented step by step using a very ambitious and efficient dissemination plan made by University of Helsinki.

In Finland Heureka, the Finnish Science Center and the University of Helsinki organized 5 seminars and conferences, 3 presentations/ demonstrations and workshops, 10 educational courses and 1 article in Luma-news. 15 of these events were local/national level and 4 international level events. Main dissemination event in Finland was the Science Circus with over 1000 students and teachers. Main validation event in Finland was the "Informal learning course" at the end of the November 2011 with 120 teacher students. All together 2295 persons participated events in Finland.

In Greece the Institute of Communication and Computer Systems (ICCS) and Ellinogermaniki Agogi (EA) organized 2 seminars and conferences, 10 presentations/ demonstrations and workshops, 6 educational courses and 1 publication. 13 of these events were local/national level and 6 international level events. Main dissemination event in Greece was the Eden Conference at the end of the October 2011 with audience of more than 70 people. Main validation event in Greece was the "Designing the School of Tomorrow Conference" in the middle of the January 2011 with more than 100 teachers and 200 students. All together 1021 persons participated events in Greece.

In Germany Fraunhofer Institute, the Institute for Applied Information Technology FIT and the University of Bayreuth (UBT) organized 5 seminars and conferences, 16 presentations/ demonstrations and workshops, 1 publication. FIT also published 5 different press releases. 11 of these events were local/national level and 11 international level events. Main dissemination event in Germany was the "Girls day Bundeskanzleramt" in Berlin in the middle of the April 2011. FIT also published the "Science Center to Go – Tangible Formulas" video. The video has been watched over 900 times since April 2011. All together 1303 persons participated events in Germany (video watchers are not included to this amount).

In Spain the University of Barcelona organized 6 seminars and conferences, 5 presentations/ demonstrations and workshops. 6 of these events were local/national level and 5 international level events. Main dissemination event in Spain was the Gacet'11 conference with over 100 participants. Main validation event in Spain was the "Faculty of Pedagogy, Department of Didactics of Maths and Experimental Science" in May 2011 with university teaching staff, university researchers and PhD students, pre-service teachers (undergraduate students). University of Barcelona had 9 web pages with over 900 visitors. All together 563 persons participated events in Spain (web page visitor are not included to this amount).

In Sweden the Linnaeus University (LNU) organized 3 seminars and conferences, 5 presentations/ demonstrations and workshops and 1 educational course. All of these events were local/national level. Main dissemination and validation events in Sweden were the "NO-Biennalen" conference in Halmstad with 300 science teachers and the "Science competition" in Växjö with 300 students with hands-on presentation for 8th grade students participating in a science competition. LNU published an article in Tidningen Näringsliv magazine, which was distributed to 30,000 readers. The magazine is for the industry and the private sector. Accessible to this magazine is for 2 million people travelling via airport, train or bus. LNU got a one page article or the SCeTGo –system trials in Sm landsposten newspaper. The newspaper has over 50,000 potential readers. All together 825 person participated events in Sweden.

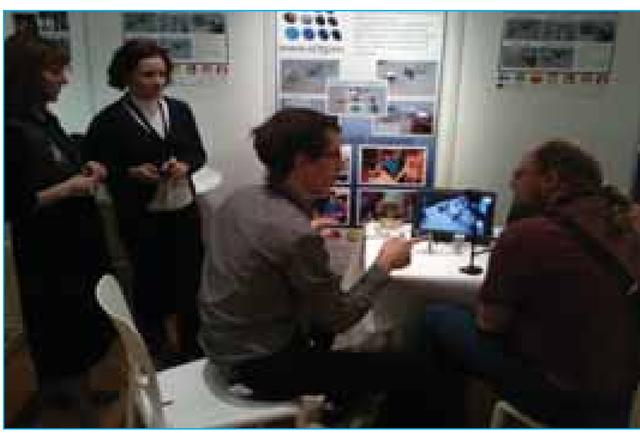
In UK the Centre for European Research (CER) organized 2 seminars and conferences, 2 presentations/ demonstrations and workshops. 3 of these events were local/national level and 1 international level event. Main dissemination and validation events in UK were the "Inventorium Education Symposium" conference in Dublin at the end of the March 2011 and the "IoP Wales 4th National Teachers" conference at the end of the June 2011 both with over 100 participants.


In Romania the Cluj County Teacher Training Centre (CCD Cluj) organized 5 seminars and conferences, 3 presentations/ demonstrations and workshops and 1 educational course. All of these events were local and national level events. Main dissemination event in Romania was the "Preuniversitaria Symposium" at the end of the March 2010 with over 147 teachers. Main validation event in Romania was the "Science and Technology week" at the middle of the November 2010 with 56 physics teacher and students. CCD Cluj published 1 press release, 1 news letter and held 1 press conference and published 3 web pages. All together 566 person participated events in Romania.

SCeTGo –project had a presentation and stand in SCIENTIX conference 6th to 8th May 2011 in Brussels, Belgium. The overall amount of participants in SCIENTIX conference was over 400. SCeTGo stand was the most popular and most visited stand in the conference. The project was introduced in ECSITE annual meeting 25th May 2011 in Warsaw, Poland to 15 science center personnel. The SCeTGo –project had a presentation in NSCF annual meeting 21st to 23th September 2011 in Reykjavik, Iceland. The presentation was held to 50 science center personnel. The project also participated in to the EDEN conference 27th to 29th October 2011 in Athens, Greece. The amount of participants visiting to SCeTGo workshops and who got information from the project was 70.

The SCeTGo –project consortium had a kick-off meeting in Helsinki, Finland. 1st consortium meeting was held in Cluj, Romania. 2nd consortium meeting was held in Athens, Greece. 3rd consortium meeting was held during the Scientix conference in Brussels, Belgium. The consortium closing conference was held after the Eden conference in Athens, Greece. The last two consortium meetings were held at the same place as the SCIENTIX and Eden conferences. Most of the consortium members were invited to these conferences and in Eden the SCeTGo –project was part of two workshops.

The SCeTGo –project was carried out by a consortium of 10 partners located in 7 different countries (Greece, Finland, Germany, Sweden, Spain, Romania and UK). These partners bring a real cross-disciplinary know-how, with expertise in e-learning, mixed reality and wearable devices, wireless networks and devices, scenario design, pedagogical research and evaluation in science teaching and applied research in implementing innovative educational techniques in schools / university environments. The project brings together top-level technological research institutions (ICCS, Fraunhofer), top-level pedagogical research institutions (LNU university, University of Helsinki, University of Barcelona, University of Bayreuth, Centre for European research), one science centre (HEUREKA) which is the top science centre in Finland and one of the most identifiable in Europe, a teacher training organization (CCD Cluj) and Ellinogermaniki Agogi a private school organization which is considered among the most active organizations of its type in an EU level.



1.6 References

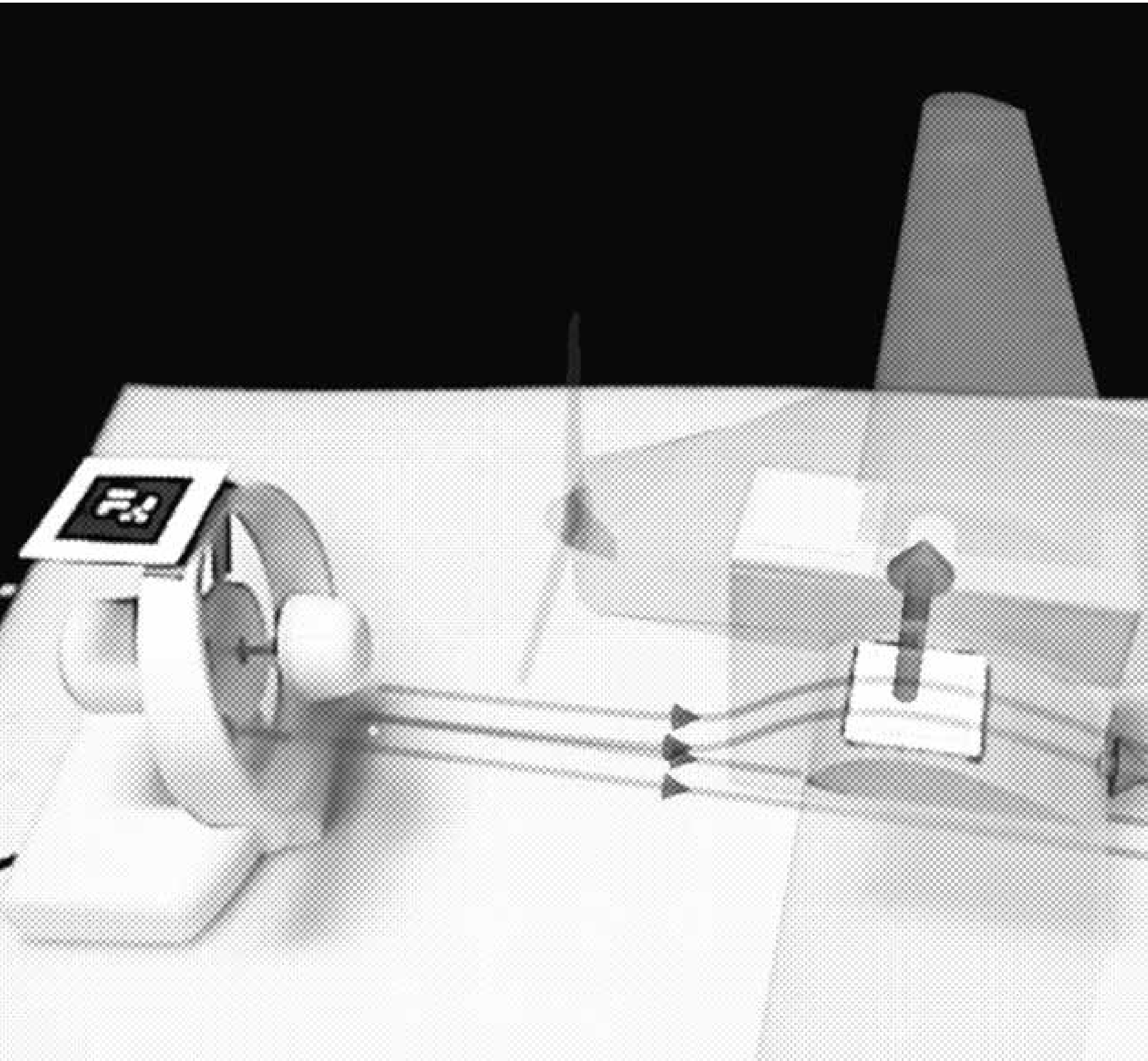
[1] Papert, S. (1991). "Situating Constructionism." In Constructionism, edited by I. Harel and S. Papert. Norwood, NJ: Ablex Publishing.

[2] Resnick, M. (1993). Behavior Construction Kits [pdf]. Communications of the ACM, vol. 36, no. 7, pp. 64-71 (July 1993).

[3] Science Center To Go official website: http://www.sctg.eu


Science Center To Go

2. The SCeTGo Technology



2.1 The Augmented Reality Technology

2.1.1 The Augmented Reality Framework

The Science Center To Go system is build on top of the MORGAN AR/VR Framework. Morgan is a component-based framework that relies on the CORBA middleware for network communication. It currently supports many devices, including mouse and keyboard as well as haptic input devices, object tracking systems and speech recognition libraries. Thus, multi-modal user interfaces can be rapidly developed and evaluated. Since Morgan provides a distributed render engine with automatic scene graph synchronization capabilities. All components are accessible from remote computers. The Morgan AR/VR Framework is a complete framework for developing AR and VR applications for many application scenarios. It consists of the following core omponents:

- Render Engine: A render engine for 3D scenes and objects with functionality for object manipulation, character animation, picking (object selection), and collision detection.
- External Scene Graphs: Support for different 3D file formats, such as VRML '97, X3D and Cal3D, is provided through external scene graphs, which map the file format specific 3D object hierarchy onto the internal scene graph of the render engine.
- Media Libraries: A number of libraries for supporting all kinds of media is available, for accessing images, videos, movies, and audio. Additionally a library for streaming RTP/RTSP video streams allows Morgan to stream augmented video streams to external video clients.
- Marvin: The AR/VR Viewer of the Morgan AR/VR Framework provides 3D render output for the render engine as well as an interface to the used input and output devices. Besides keyboard and mouse navigation, stereo properties, video background, head tracking, interaction and visualization capabilities are easy to configure. The component-based architecture of Morgan makes it feasible for Marvin to load all components even external applications via a plug-in mechanism.
- Input and Output Devices: All input and output devices in Morgan are realized using an abstraction layer. Thus it is easy to integrate new devices or access existing plugins. The devices comprise Mouse, Keyboard, InertiaCube, Marker Based Computer Vision tracking, EDAS, GPS, Audio, Speech etc.

The MORGAN AR/VR Framework has been taken as a basis for SCeTGo application layer. On top of this layer the specific adaptation for each exhibit is achieved through interaction scripts (Behavior UI-Scripts) and hardware configuration files as visualized in the diagram below.

<table>
<tr><td rowspan="4">Science Center To Go Exhibit Loader</td><td colspan="3">Science Center To Go exhibit application logic</td></tr>
<tr><td colspan="3">SCeTGo basic application layer</td></tr>
<tr><td>Rendering</td><td>Tracking</td><td>Scripting</td></tr>
<tr><td colspan="3">MORGAN AR/VR framework</td></tr>
</table>

Figure 2.1: *The Science Center To Go system building on Fraunhofer's MORGAN AR/VR Framework*

The SCeTGo basic application layer provides access to basic modules of Morgan which comprise the rendering engine, tracking and scripting. Based on this layer the application logic for each exhibit was implemented using the Morgan behaviour scripting language. The Morgan behaviour scripting language is a data flow object oriented implementation for creating interactive AR applications.

The Morgan modules used for the Science Center To Go application are listed in Table 2.1

Amount	Entity
1	**License for Morgan component:** IDL:fit.fraunhofer.de/Morgan/TrackerBaseFactory:1.3
1	**License for Morgan component:** IDL:fit.fraunhofer.de/Morgan/ViewerWrapper:1.3 component
5	**License for Morgan component:** IDL:fit.fraunhofer.de/Morgan/NodePickingQuery:1.3.
1	**License for Morgan component:** IDL:fit.fraunhofer.de/Morgan/MousePickingQuery:1.3
1	**License for Morgan component:** Morgan Behavior support Plugin
1	**License for Morgan component:** Morgan Core Plugin
1	**License for Morgan component:** Morgan Media Open IL Plugin
1	**License for Morgan component:** Morgan RSG Wrapper Plugin
1	**License for Morgan component:** Morgan Mouse Keyboard Plugin
1	**License for Morgan component:** Morgan X3D Plugin
1	**License for Morgan component:** Morgan Viewer Wrapper Plugin
1	**License for Morgan component:** Morgan Tracker Base Plugin1

Table 2.1: *Morgan Modules used for Science Center To Go*

2.1.2 Making Augmented Reality Tangible

In order to make AR tangible we are facilitating a 3D printer for rapid prototyping. With such a printer the creation and modification of tangibles take three steps as shown in Figure 2.2

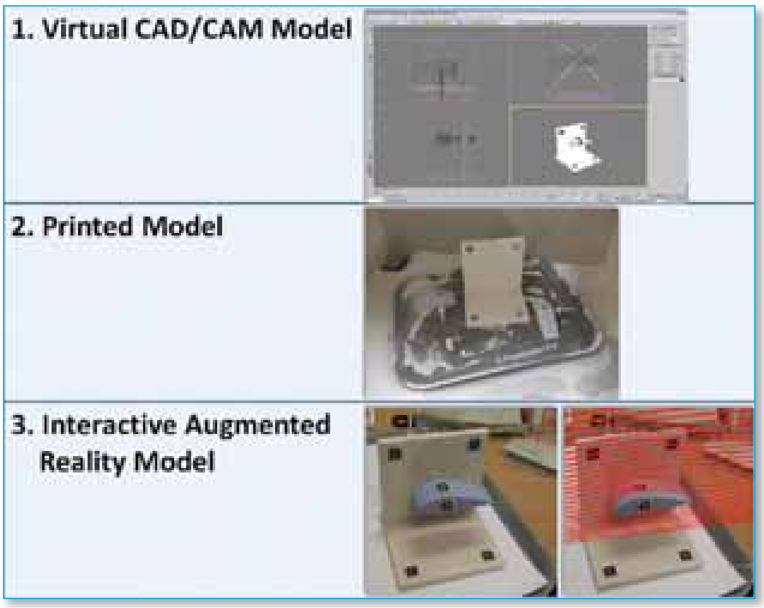


Figure 2.2: *Three steps involved for rapidly creating and modifying a tangible prototype for a Science Center To Go exhibit. This example shows the first generation of the airfoil wing – which is now in its 6th generation.*

First each tangible is virtually modelled in 3D, then it is printed out using a 3D printer. The print out model serves as a tailor made physical representation for the virtually added 3D AR content. Fiducial markers are used to register physical models in 3D.

The following software items and digital content that is part of the Science Center To Go System: is listed in Table 2.2

Amount	*Entity*
1	*Fraunhofer FIT Morgan Framework - Science Center To Go specific release (Further detailed in Error! Reference source not found.*
1	*Science Center To Go exhibit startup GUI*
5	*Scripted miniature exhibit application logic, Multimedia content consisting of 3D Models, 2D images, and Audio files*
1	*Digital version of instructions and troubleshooting*
1	*Digital version of maintanence instructions*

Table 2.2: *Suticase Software and Digital Content*

2.2 The SCeTGo Suitcase: Equipment & Software

With the goal of creating a Science Center in a suitcase for take away to deliver rich experiences at hand, we started off with the first prototype a miniaturized airfoil exhibit, and iteratively added further exhibits and refined former ones. We conducted 3 major development cycles, each consisting of several iterations per exhibit.

Figure 2.2: *Suitcase with 5 exhibits.*

The suitcase's dimensions are 390 mm x 290 mm x 12,5mm, it includes the parts listed in Table 2.3.

Amount	Entity
1	Dell Laptop "Latitude XT2" with touchscreen and solid state disc
1	Logitech Portable Webcam C905 on a tripod
5	Minitaure Exhibits as further detailed in List 2 to 6
1	Custom foam Inlay
1	Paper version of instructions and troubleshooting
1	Paper version of maintanence instructions
1	White foam base (380mm x 280mm x 10mm)

Table 2.3 *Hardware of the Suitcase*

Figure 2.3:*The Science Center To Go suitcase and contents (laptop not shown)*

The Science Center To Go suitcase contains the resources, which consist of a laptop computer, a webcam and five small-scale science centre exhibits (miniatures):

1. Mini-fire truck (the Doppler effect)
2. Mini-double cone (classical mechanics)
3. Mini-wing (wing dynamics)
4. Mini-double slit (quantum mechanics)
5. Mini cooler & heater (kinetic theory of gases)

The miniatures are set up one at a time in the webcam's field of view. The webcam creates an image on the laptop screen. Software adds an overlay to the image. As the miniature is manipulated, the overlay changes in response to the movement. The overlay depicts an aspect of the scientific phenomenon under investigation, for example trigonometric information or waves (Figure 2.4). This process of adding unseen elements to the image on the screen is the augmented reality (AR).

The suitcase is a self-contained science centre that can be used in schools and science clubs or by individuals in their homes. The aim is to stimulate interest in science and to promote techniques of scientific inquiry, so that subsequent visits to a science centre are more productive and rewarding. The suitcase can also be used to follow up a visit to a science centre, or as a stand-alone resource when a visit is not possible.

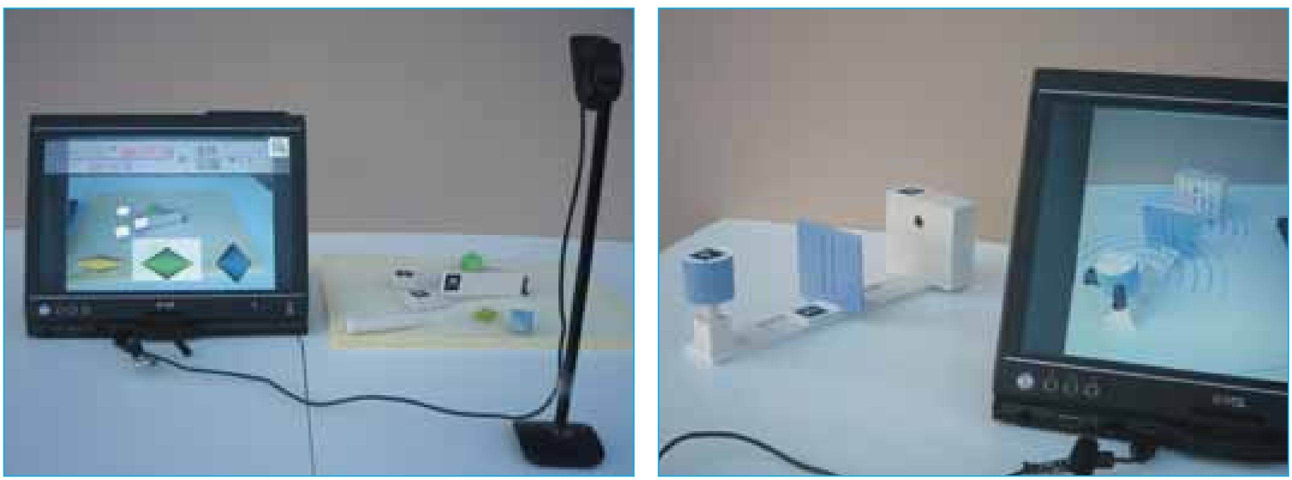


Figure 2.4: *The AR adds elements to the miniatures*

The suitcase is designed to be used by anyone who can manipulate the parts safely. In this manual there are some activities suggested for use in schools and colleges with the following groups of learners:

- Younger learners, aged 8 to 13
- Older learners, aged 12 upwards, studying general science subjects
- Science specialists, aged 14 upwards, working towards specific science qualifications

The aim of the SCeTGo project is to promote interest in science and methods of scientific inquiry, so the activity for users could be to work out how to use the miniatures and guess or deduce what they are showing, rather than to follow instructions. In all the activities learners have the opportunity to realise that the best way to make investigations is to make one change at a time and make careful observations.

2.2.1 The Laptop

Figure 2.5: The SCeTGo menu on the rotatable touch screen

The suitcase includes a Dell laptop loaded with Microsoft XP and the AR software for the miniatures. It is also loaded with other software such as Microsoft Office and Internet browsers. It has a touch screen that can swivel round. When the computer is switched on the user is presented with a visual menu from which to choose a miniature (Figure 2.5). Users can return to this menu after using a miniature by touching the SCeTGo logo in the top right hand corner of the screen.

There is a link to a visual help guide and a video of all the miniatures in use from the menu screen. The same video is on the SCeTGo website, divided up into individual miniatures. Links are given in this manual. This is a very useful starting point for teachers, and a useful troubleshooting resource, but please note that the miniatures and AR have been updated since this video was recorded. Teachers may not wish their students to watch the video before they conduct their investigations.

Users can make screenshots by simultaneously pressing the Fn and Druck (F11) keys. The images can then be viewed in Microsoft Office, accessible from the Start menu.

2.2.2 The Webcam

The suitcase also includes a USB webcam with a stand. The webcam needs to be assembled, and then positioned so that:

1. The AR markers are detected by the software;
2. The screen shows a good display of the whole miniature (and in some cases, the space around it);
3. It is stable and does not fall over easily. Once a good position has been found it is a good idea to stick the stand to the surface with adhesive tack or masking tape.

Figure 2.6: *The webcam and stand*

Users can experiment to find the best orientation. In general locating the camera above the miniature, pointing down at an angle, works well (see Figures 2.4 & 2.6).

2.3 The SCeTGo Miniatures

The miniatures are small plastic models (Figure 2.7).

Each miniature has two or more AR markers (the black and white shapes in Figures 2.4 & 2.7) that are recognised by the software through the webcam. The markers disappear from the screen when the AR software detects them (see Figure 2.4) and in some cases are replaced by images. The augmented elements are computed according to the position of markers relative to each other, and to their distance from the webcam. The software responds to the AR marker and not the object itself, so if the marker is not in the correct position on the miniature the AR will not work correctly.

It is important that:

1. The system is set up on a flat, sturdy surface that does not shake.
2. The level of illumination is good. A brightly lit classroom is usually good enough, but the AR might not work if there is too much light.
3. There is a clear line of sight between the webcam and the markers. The users need to learn to use the miniatures without breaking this.
4. The markers are in perfect condition. For this reason users should avoid touching them. They can be printed out from this manual (Appendix B).
5. Each miniature is used with the correct software, chosen from the SCeTGo menu.

The following sections contain a description of each miniature in turn, with instructions for setting up and using them.

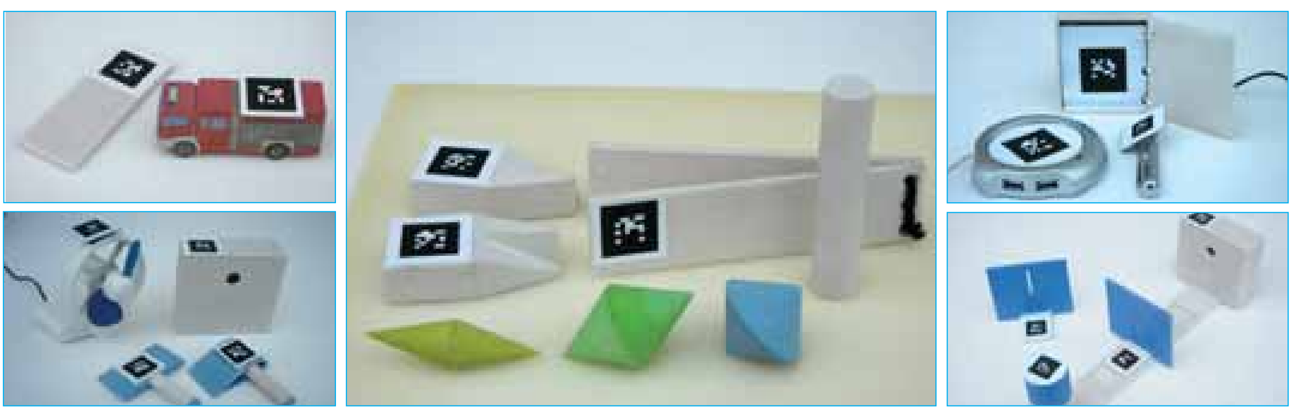


Figure 2.7: *The miniatures: mini-fire truck, mini-double cone, mini-wing, mini-double slit and mini-cooler & heater*

2.3.1. Mini-fire truck (the Doppler effect)

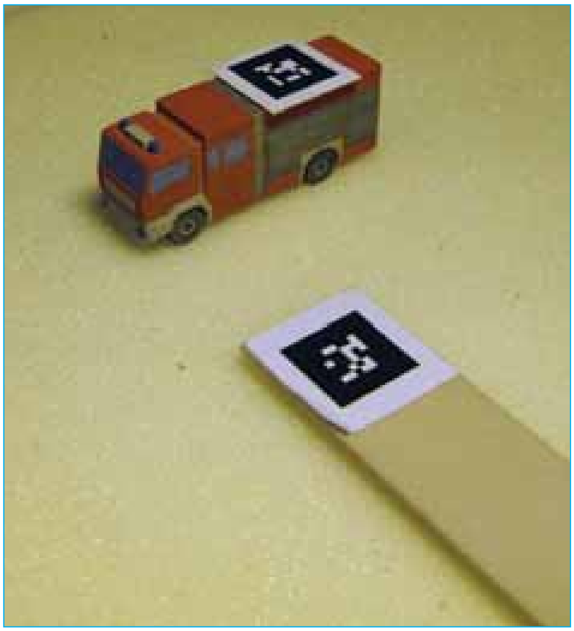


Figure 2.8: *Mini-fire truck*

Online demonstration: http://www.sctg.eu/miniature2.asp

The mini-fire truck exhibit consists of a model fire truck and a strip with an AR marker representing a microphone (Figure 2.8). The "microphone" is the lid of the mini-wing box.

There are three elements to the AR:

1. Sound waves coming from the fire truck's siren
2. the fire truck's two-tone siren, as detected by the microphone
3. The frequency of the sent and received frequencies (Hz), together with the equation

$$f_R = \frac{f_S}{1 - {}^{v}/_{c}}$$

where fR is the received frequency, fs is the emitted frequency, v is the relative velocity and c is the speed of sound.

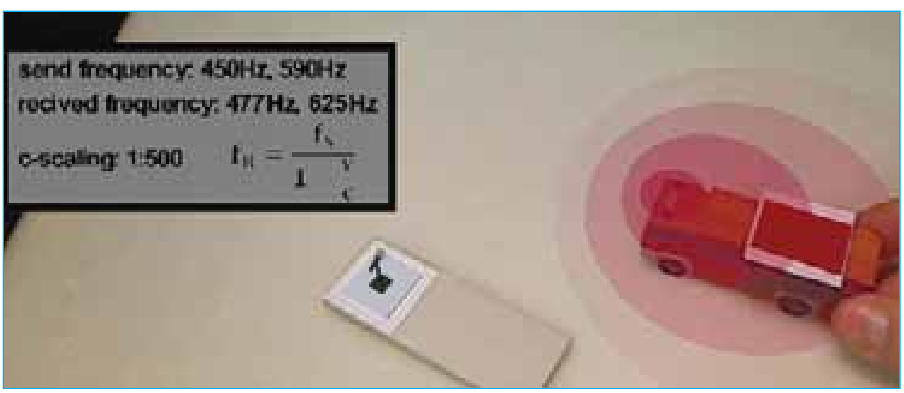


Figure 2.9: *Fire truck as seen on the screen*

Sound waves are represented by concentric circles that travel away from the virtual sound source, a two-note siren at the front of the fire truck. The circles are red at the source and become paler as they travel away (Figure 2.9). On the screen the microphone AR marker appears as a microphone that detects the sound from its position relative to the source.

The pitch of the sound is represented by the distance between the circles as they reach the microphone. When the vehicle and observer are stationary the "sound waves" come from the siren in evenly spaced concentric circles (Figure 2.10), and the pitch of the two notes detected by the microphone is constant, with sent and received frequencies of 450 and 590 Hz.

If the fire truck is moved forwards across the frame of the webcam, the circles are closer together in front and further apart behind. The pitch of the sounds is higher as the vehicle moves towards the microphone (Figure 2.11), and lower as it moves away (Figure 2.12). The higher the velocity of the fire truck is relative to the microphone, the greater the change in pitch. Thus the frequencies displayed on the screen are correspondingly higher or lower, as appropriate. In Figure 2.9 the fire truck is moving towards the microphone and the received frequencies are 477 and 625 Hz.

The miniature can also be used to show the reciprocal effect, that if the fire truck remains stationary and the microphone is moved, the pitch of the sound also changes, the relative velocity being the determining factor in the pitches and frequencies detected. The AR will also respond appropriately when both the sound source and microphone are moved at the same time.

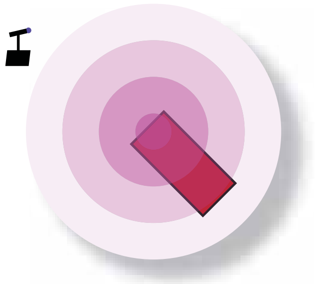


Figure 2.10: Stationary fire truck

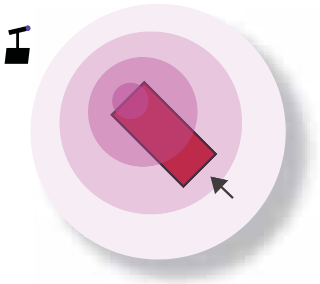


Figure 2.11: Fire truck moving towards microphone

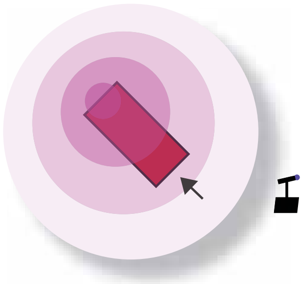


Figure 2.12: Fire truck moving away from microphone

To use the miniature:

1. Choose the fire truck from the SCeTGo menu
2. Position the webcam so that the fire truck and microphone can be moved about 30 cm and still remain in the camera's field of view. Wait until the AR is stable.
3. Move the fire engine and observe the pattern of sound waves, the pitch of the siren (as detected by the microphone) and, if desired, the frequencies. The AR works best if the fire truck is moved slowly.
4. Move the microphone and note the effect on the pitch of the siren and on the frequencies of the sounds.
5. If desired, turn the sound on and off by simultaneously pressing Fn and Entf on the keyboard.
6. Touch the SCeTGo logo on the screen to return to the main menu.

Younger learners who have not yet learned about the wave nature of sound could be asked what they think the circles represent. Careful experimentation and observation could lead them to make the connection between the pitch of the sound and the spacing of the circles.
Older learners could be shown a film clip of the Doppler effect, and then asked to use the miniature to explain the effect:
a) when the fire truck is moving, and
b) when the observer is moving.

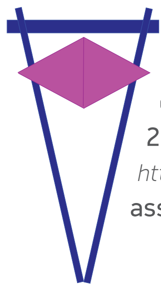
Science specialists should be able to explain why the perceived frequency of a sound relates to the relative velocity of source and observer. They should be able to explain the equations associated with the phenomenon.

Amount	Doppler Exhibit
1	Miniature fire truck (72mm x 30mm x 20mm)
1	Lid fitting the Box. The as same used List 2 – Bernoullis Exhibit Hardware, List 4 – Youngs Exhibit Hardware

Table 2.4 *Doppler Exhibit Hardware*

2.3.2 Mini-double cone (classical mechanics)

Online demonstration: *http://www.sctg.eu/miniature5.asp*



This is based on a seventeenth century puzzle known as Leybourn's uphill roller. It consists of two cones joined together at their bases, on rails that slope and diverge. If the double cone is placed on the narrow, lower end of the track it travels along the track, appearing to travel uphill (Figures 2.13 and 2.14). There is an excellent description of it online from the University of Cambridge at *http://plus.maths.org/issue40/features/uphill/index-gifd.html*. together with the history, animations and associated trigonometry.

Figure 2.13: *Roller viewed from above*

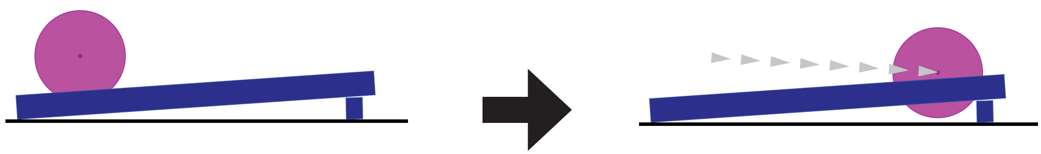


Figure 2.14: *Uphill roller viewed from the side, starting and finishing positions*

The roller is normally presented as an exhibit whose dimensions are fixed, the objective of which is simply to solve the puzzle. Why does the roller roll uphill? Why does it appear to break the laws of physics? The answer is of course that it doesn't. The roller moving up the divergent tracks is actually falling (grey arrows in Figure 2.14). The divergence of the rails overbalances their upward slope, allowing the centre of mass of the cone to drop. This is not obvious unless the exhibit is observed carefully from the side. The SCeTGo miniature consists of a set of rails whose slope and angle of divergence can be varied, together with three double cones and a cylinder (Figure 2.15).

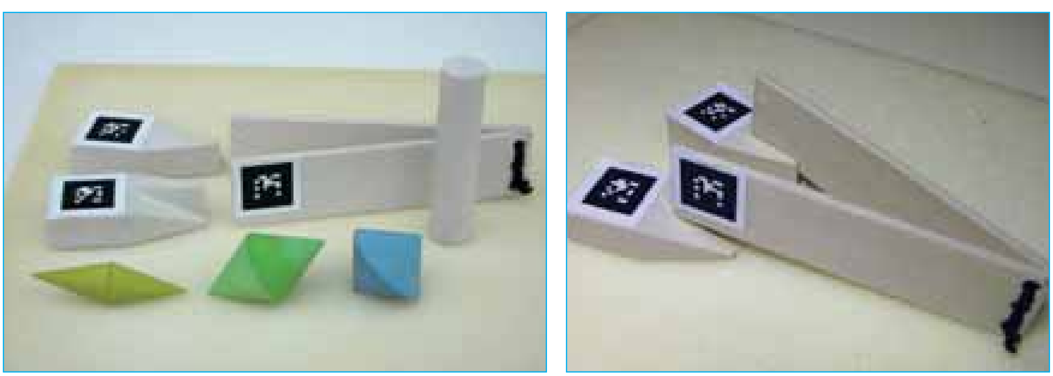


Figure 2.15: *Components of the mini-double cone and the rail setup*

The angles of the apices of the 3 cones, 2γ (Figure 2.16), are 30°, 60° and 90°. The AR measures two variable angles, α, the angle of inclination of the rails (Figure 2.17), and β, half the angle of divergence of the rails (Figure 2.16). The cylinder is present for comparison purposes, as it always rolls down the slope.

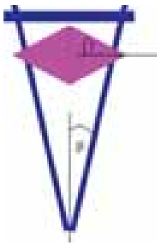


Figure 2.16: *Angles β and γ*

Figure 2.17: *Angle α*

The AR computes:

$$\frac{\tan(\beta) \times \tan(\gamma)}{\tan(\alpha)}$$

If this is >1 then the double cone rolls up the rails. If it is <1 the cone rolls down. In Figure 2.18 it is balanced. The colours of the elements of the formula onscreen correspond with the colour of the cone and the angles of the miniature (Figure 2.18).

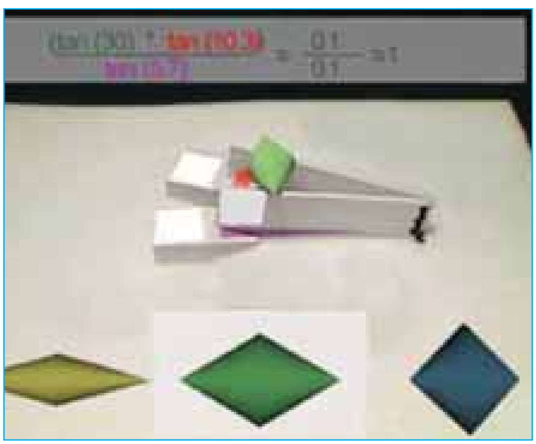


Figure 2.18: *The double cone as it appears on the screen*

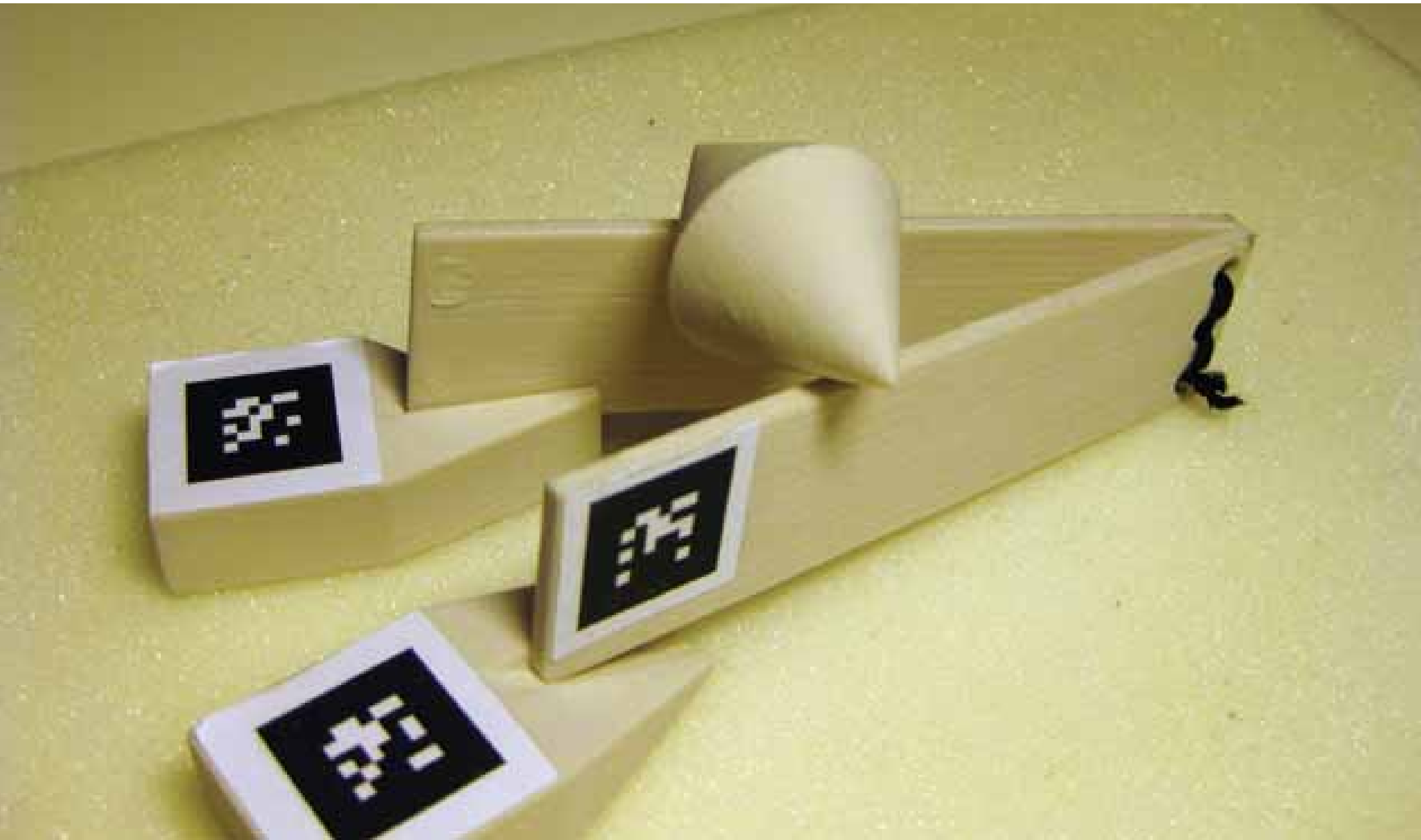
To use the miniature:

1. Put the objects on the foam mat, or on another suitable high-friction surface, and set them up as shown in Figures 2.15 and 2.18, with the AR marker on the left hand side of the rails. The edges of the rails should butt up evenly against the supports.
2. Locate the webcam so that it detects the three AR markers. Choose the double cone from the SCeTGo menu.
3. Choose a cone and indicate on the screen which cone is in use.
4. Put the cone on the rails and see whether it goes up or down the slope.
5. Experiment with the miniature, changing angles α and β and observing how the cones and the cylinder travel on the rails.
6. Observe the effect the changes have on the AR.
7. Touch the logo on the screen to return to the main menu.

This is a complex model and there are many options for activities in the classroom. Younger learners could look at the one cone and the rails without the AR and try to work out why the cone travels up the rails. They could express their findings in words rather than mathematical formulae. Older learners could discover that if the computed formula is greater than 1 the roller goes up the rail. They could make and record observations using one of the double cones, predict what the results will be for the others and test their hypotheses. Learners could also be asked to predict how the system would be affected by other changes, for example if the double cone was partially filled with mercury. Science or mathematics specialists could study the trigonometry, define the conditions needed to make an uphill roller, and make and test their own.

Amount	mini-Double cone Exhibit
2	Railes connected with each other at one end (*)
2	Ramps (*)
1	Cylindrical Wing (*) used as canon control. The same as used in List 2 – Bernoullis Exhibit Hardware
1	Yellow double cone (15°)
1	Green double cone (30°)
1	Blue double cone (45°)

Table 2.5 *Double Cone Exhibit Hardware*



2.3.3 Mini-wing (wing dynamics)

Online demonstration:: *http://www.sctg.eu/miniaturel.asp*

The miniature aeroplane wing (mini-wing) consists of an object shaped like the section of an aeroplane wing, connected to a box (Figure 17). The angle of the wing with respect to the ground can be changed. There is also a fan that is powered through a USB connection, and a flat wing for comparison purposes. This miniature is designed with a specific activity in mind, which is to help explain why aeroplanes can fly and to determine the angle of the wing that maximises the lift afforded to the aeroplane.

Figure 2.19 *Components of the mini-wing miniature and wing set up for use*

The AR measures the angle of the wing with respect to the horizontal and overlays five elements to the image of the wing on the laptop screen (Figure 2.20):

1. The body of the aeroplane.
2. The relative speed and direction of airflow above and below the wing. Curved green lines represent the direction of airflow. The blue and red arrows on these lines represent the relative speed of air above and below the wing. The airflow speed increases as the fan is moved nearer to the aeroplane.
3. Uplift. The solid green arrow pointing upwards from the wing represents the force acting to lift the wing.
4. Drag. The solid pink arrow represents the force acting against the wing's forward motion. If this is great the plane will stall.
5. Air molecules being sucked through the fan.

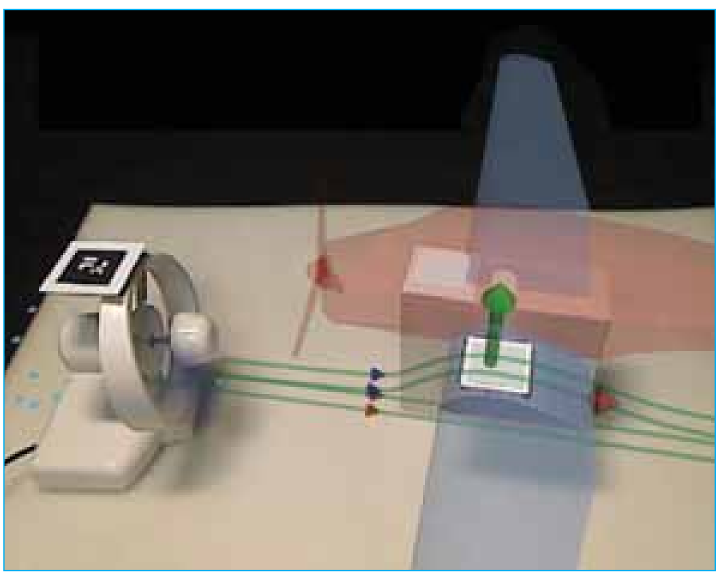


Figure 2.20 *The mini-wing as it appears on the screen*

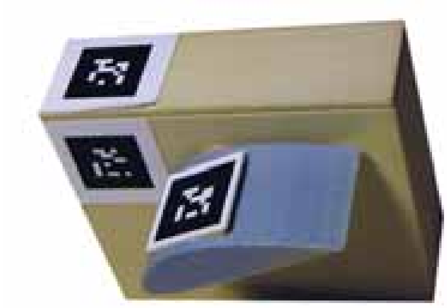
To use the miniature:

1. Take the mini-wings out of their box, and then insert the shaped wing into the holes that go through the box. Put the lid on the box with the AR marker on the left (Figure 2.19).
2. Plug the fan into a USB port.
3. Choose the mini-wing from the SCeTGo menu.
4. Position the webcam so that the wing is in the centre of its field of view and the fan to the left.
5. Check that all the AR markers are detected by the webcam.
6. Adjust the angle of the wing and observe the effect this has on the AR. Allow the AR to stabilise between adjustments.
7. Replace the shaped wing with the flat wing and observe the differences.
8. Touch the SCeTGo logo on the screen to return to the main menu.

The main activity with this miniature is to determine the optimum angle of attack for the wing, the one that gives optimal lift, which is of the order of 15° to 20°. Older learners can relate this to Bernoulli's principle. Science specialists could research other factors that have been proposed as contributing to the optimum shape for airfoils and their relative importance.

Amount	**Bernoullis Exhibit**
1	Box (80mm x 70mm x 30mm)
1	Lid fitting the Box mentioned above
1	Curved Wing (*)
1	Flat wing (*)
1	Cylindrical Wing. The same as used in List 4 – Youngs Exhibit Hardware(*)
1	USB powered Fan – Conrad Electronic Model no. PC-5001

Table 2.6 *Bernoullis Exhibit Hardware*



Learners can also use this miniature to explore and propose theories about how wings enable aeroplanes to fly. It may be useful to carry out an experiment from which the pupils discover that objects are drawn towards faster-moving airstreams. Alternatively they could base theories on the number of air molecules striking the upper and lower surfaces of the wing.

2.3.4 Mini-double slit (quantum mechanics)

Online demonstration: *http://www.sctg.eu/miniature3.asp*

This miniature is based on Young's double slit, which the polymath Thomas Young used in the nineteenth century to demonstrate the wave nature of light. He directed a narrow monochromatic light source at two slits and observed interference patterns on the observation screen. Since then experiments have been carried out firing electrons through double slits to define and explore their wave-particle duality.

The aim of the mini-double slit is to use AR to simulate the behaviour of particles and waves passing through single and double slits.

There is a simple explanation of this topic in animated format at *http://www.youtube.com/watch?v=DfPeprQ7oGc*

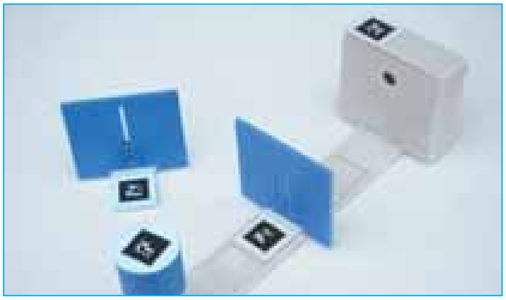


Figure 2.21 *Miniature with double slit screen in place*

The miniature (Figure 2.21) consists of:

- a background box (the same box that is used in the mini-wing miniature);
- a support for the screens with a track for the slits to move in;
- two interchangeable screens, with single and double slits;
- a "cannon" that can be rotated to fire large particles, waves or electrons.

There are AR markers on the background box, on each screen and on the cannon. There are three modes of AR:

- wave mode; • particle mode; • electron/wave-particle duality mode.

In particle mode a single or double line of particles appears on the background box, representing particles passing through one of the slits and striking the background. The thickness of the lines builds up with time (Figure 2.22).

In wave mode the AR shows the effect of waves originating from the cannon The lines on the background of the double slit version represent vertical extensions of the points where the waves have interfered constructively (Figure 2.23).

In electron mode electron particles are fired at the slits, and the pattern on the back when there are two slits shows several rows of particles building up, showing that there are interference effects consistent with wavelike properties.

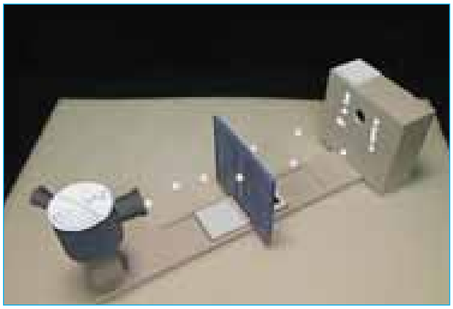


Figure 2.22: Double slits in large particle mode

Figure 2.23: Double slits in wave mode

To use the miniature:

1. Set up the miniature as shown in Figure 2.21 using either the single or double slit. The slit that is not in use should be out of the field of view of the webcam. The background box should be oriented so that the AR marker is to the left.
2. Position the webcam to view the miniature. The AR does not extend beyond the boundaries of the miniature, so it can fill the screen. Choose the mini-double slit from the SCeTGo menu.
3. Choose wave, large particle or electron mode by rotating the top of the cannon.
4. Observe the AR. In particle and electron modes observe the pattern building up on the background box.
5. Observe the effect of moving the slit along the track.
6. Adjust the webcam position to view the AR from different angles. This is particularly useful for the waves.
7. Repeat with different slits and options.
8. Touch the SCeTGo logo on the screen to return to the main menu.

Younger learners could use this in wave and particle modes to predict what will appear on the screen and then to use the AR to find out if they are correct. For science specialists this miniature could serve as an introduction to wave-particle duality. Pupils could try to explain how electrons travel through the double slit, and deduce whether you can predict where the next electron will appear.

Amount	Youngs Exhibit
1	Box (80mm x 70mm x 30mm). Same as used in List 2 – Bernoullis Exhibit Hardware
1	Lid fitting the Box mentioned above. (*) The same lid is also used for the Doppler exhibit
1	Cylindrical Wing used as canon control (*). The same as used in List 2 – Bernoullis Exhibit Hardware
1	Base fixation rail
1	Slidable double slit board (*)
1	Slidable single slit board (*)

Table 2.7 *Youngs Exhibit Hardware*

2.3.5 Mini-cooler & heater (kinetic theory of gases)

Online demonstration: http://www.sctg.eu/miniature4.asp

Figure 2.23 *Fridge, hotplate and thermometer*

This miniature consists of a tiny working USB cooler and hotplate together with a thermometer (Figure 2.24).

The purpose of the miniature is to visualise how the speed of gas molecules changes with temperature. There are three AR markers, one on each element of the miniature. The AR shows representations of molecules moving in the vicinity of the thermometer (figure 23). The software detects the proximity of the thermometer to the hotplate or the fridge, and varies the speed of molecule movement accordingly.

The screen also shows a graph of molecule speed against temperature, based on the equation: $v = 20.5\sqrt{\theta+273}$ where v is the molecule speed in m/s and θ is the temperature in °C (Figures 2.25 and 2.26). A red line on the graph corresponds to the temperature on the AR thermometer.

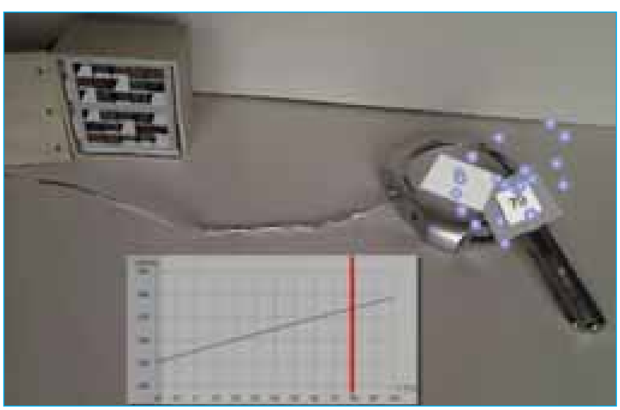


Figure 2.25 Screenshot of the mini-cooler & heater

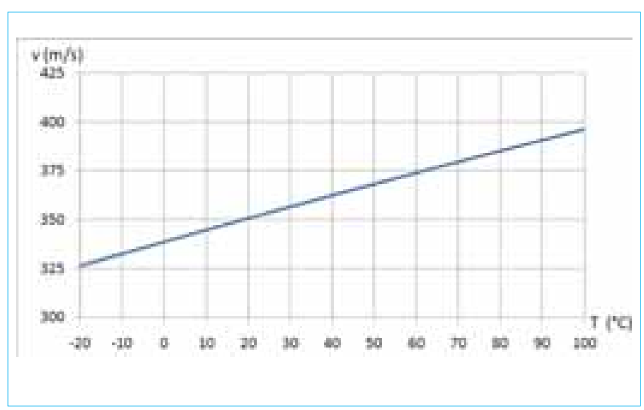


Figure 2.26 *Graph of molecule speed against temperature*

Please note that on the screen:

1. The temperatures are theoretical and are not the actual temperatures of the hotplate, fridge or room.
2. In order to illustrate the underlying principles, the molecule speed observed is many orders of magnitude slower than the actual speed.
3. The difference in speed at different temperatures is exaggerated.

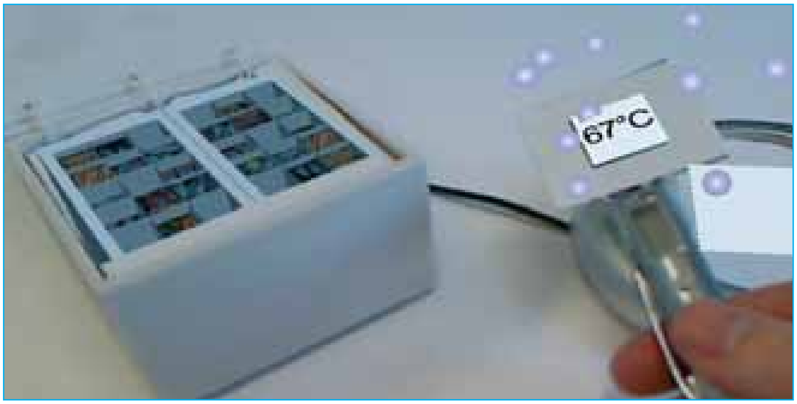
To use the miniature:

1. Plug the heater and the fridge into USB ports.
2. Push the button on the heater to turn it on if necessary.
3. Choose the mini-cooler & heater from the SCeTGo menu.
4. Put the three components in the field of view of the webcam.
5. Move the thermometer between the two appliances and observe the changes in the AR. The AR also works with only one appliance and the thermometer.
6. Touch the SCeTGo logo on the screen to return to the main menu.

Younger learners can make observations and suggest interpretations for the AR. What do the dots represent? How does their speed change? Why does it change? Science specialists can relate this to the kinetic theory of gases, covering the gas constant, Avogadro's number and the Boltzmann constant.

Amount	**Boltzmann Exhibit**
1	USB powered heating surface (*)
1	USB powered cooling element(*)
1	BaseTech Mini 1 Infrared Thermometer (*)

Table 2.8 *Boltzmann Exhibit Hardware*



2.4. Frequently asked questions

What should I do if:

- I can’t find enough USB ports?

There are USB ports at the back and on the side of the laptop. The mini-heater is also a USB hub with four ports.

- the webcam lead is too short to allow me to position the miniature where I want it to be?

You can swivel the laptop screen round. This gives more flexibility in positioning the miniatures, laptop and webcam. Alternatively, use one of the mini-heater’s USB ports to extend the range of the camera.

- I want to turn off the sound on the mini-fire truck?

Press the Fn and Entf keys simultaneously.

- there doesn’t seem to be an AR marker for the microphone (mini-fire truck)?

This marker is also the lid for the mini-wing box.

- the AR is giving unrealistic results (mini-wing, mini-double cone)?

The orientation is important in these miniatures. In the mini-wing box and the rails for the double cone the AR marker must be to the left. On the double cone check that the rails:

- rise to the same point on the rail supports;
- are butted up firmly against the rail supports.

- the waves and particles are not appearing on the background box (mini-double slit)?

The orientation is important in this miniature. The AR marker on the background box (mini-wing box) must be to the left.

- the AR markers have become discoloured/torn/dirty?

You can print out new ones. They are all given in Appendix B. These must have the exact size and position as the original markers. This is particularly important for the double cone where small changes in orientation affect the calculation of the angles.

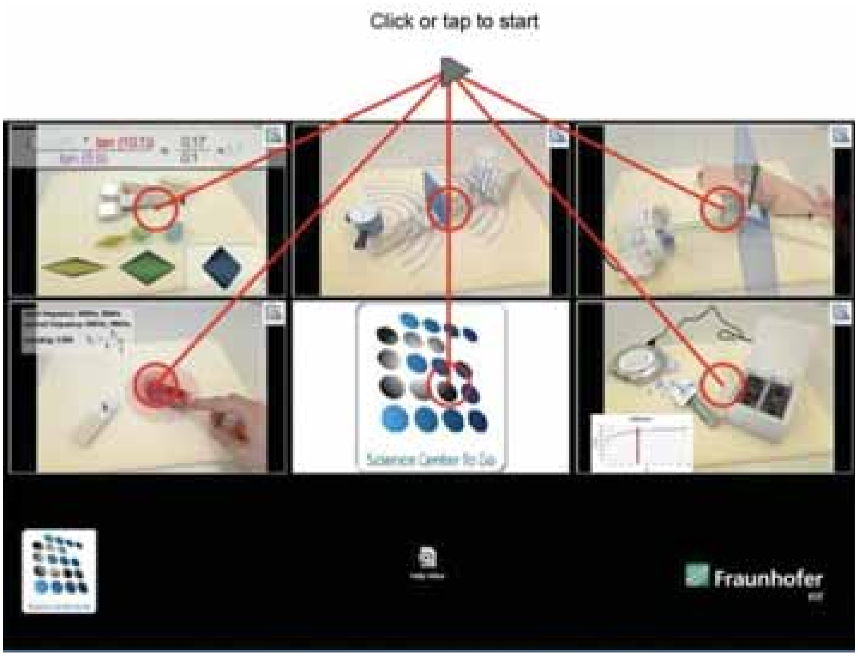
- the AR is unstable/flashing?

The light level may not be adequate. You may need a spotlight to increase illumination, or to move the equipment away from direct sunlight to decrease it. If this does not solve the problem one or more AR markers may need to be replaced.

2.5. SCeTGo visual help and troubleshooting

Start

Turn on computer and set up system



Main screen - It is a touch screen

Stop

Click or tap to stop exhibit

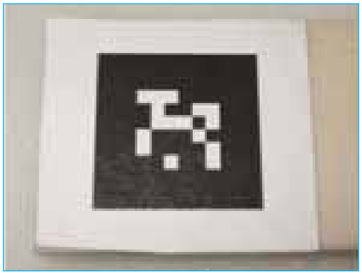
Put things back into place

Turn off computer

Troubleshooting

good Good light conditions and well illuminated AR markers

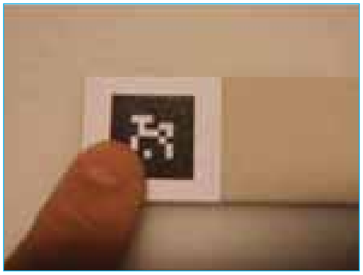
Steep camera angle



Good light conditions

not so good Bad light conditions and poorly illuminated AR markers

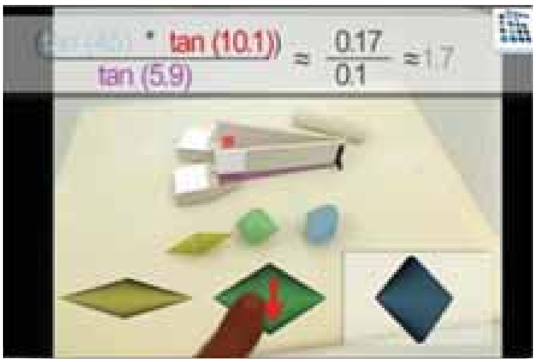
Shadow edges on markers



Occlusion of markers

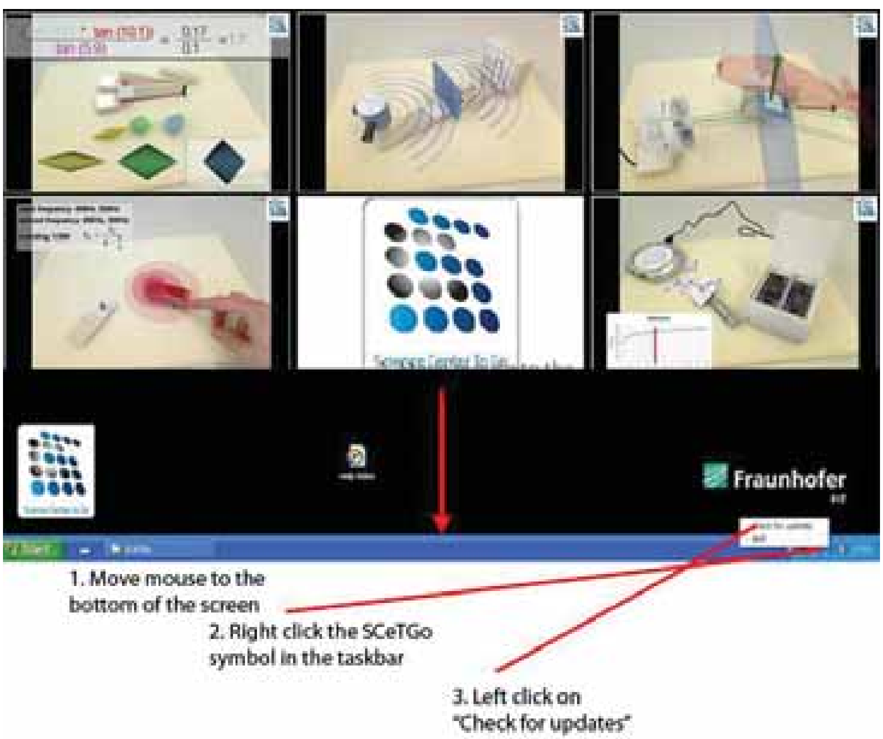
Markers are not fully visible in the camera image

Problems



The touch screen does not work

If the touch screen does not react on tapping try swiping



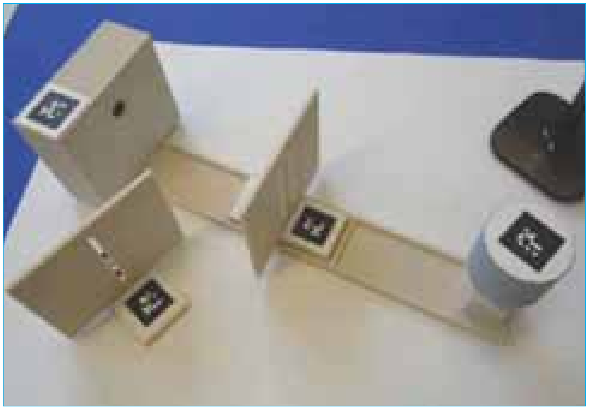
How do I update the system?

Follow instructions below

2.6 Augmented Reality Markers

The AR may not work well if the markers are not in perfect condition. If they become damaged you can reprint and replace them.

Mini-double slit



01 / Box

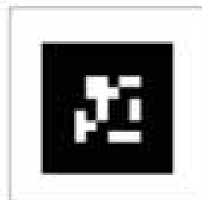
08 / Single Slit

09 / Double Slit

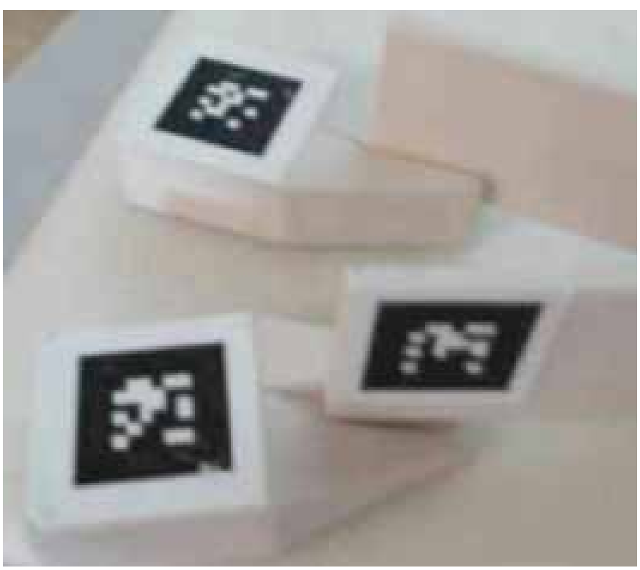
15 / Cannon Control

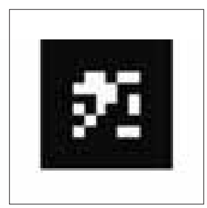
Mini-Fire truck

The microphone AR marker is the box of the mini-wing and mini-double slit

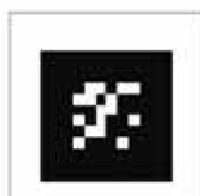


Mini-double cone





06 / Ramp B



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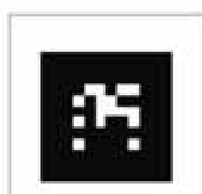
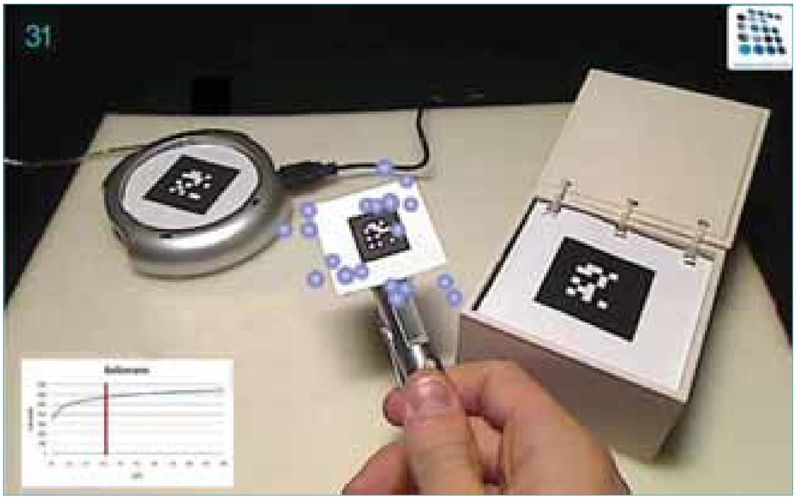
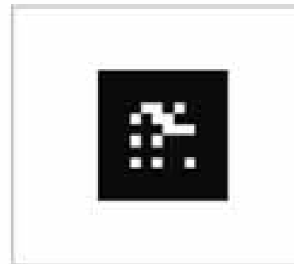


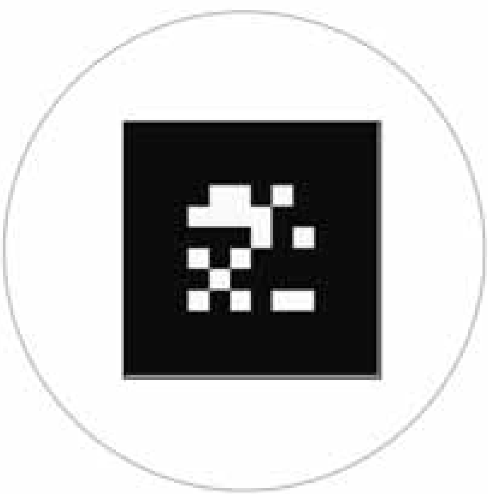
04 / Base

Mini-cooler & heater





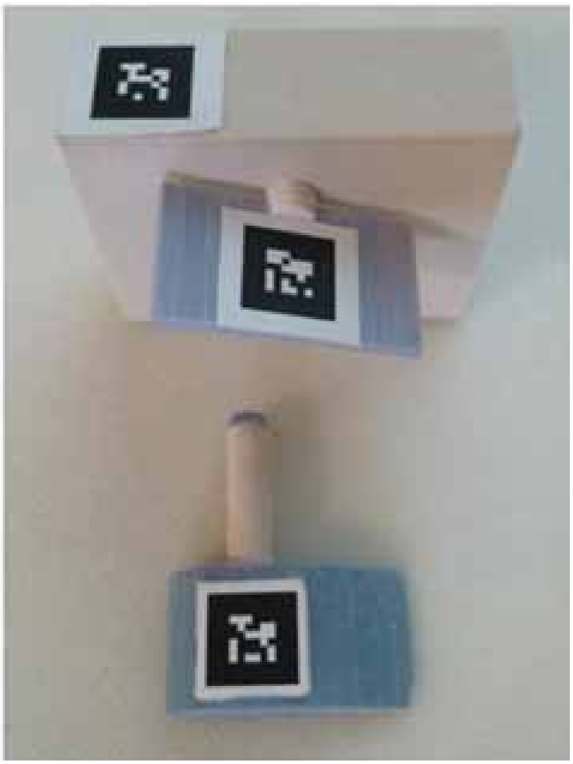
14 / Thermometer

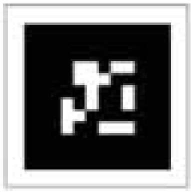


12 / Heater

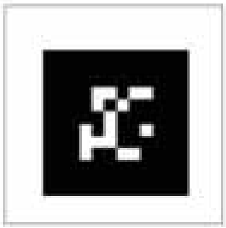
13 / Cooler

Mini-wing

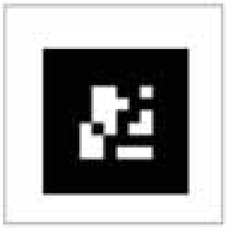


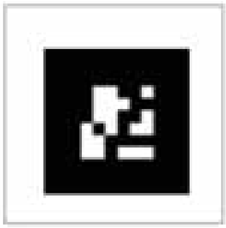


00 / Wing



01 / Box

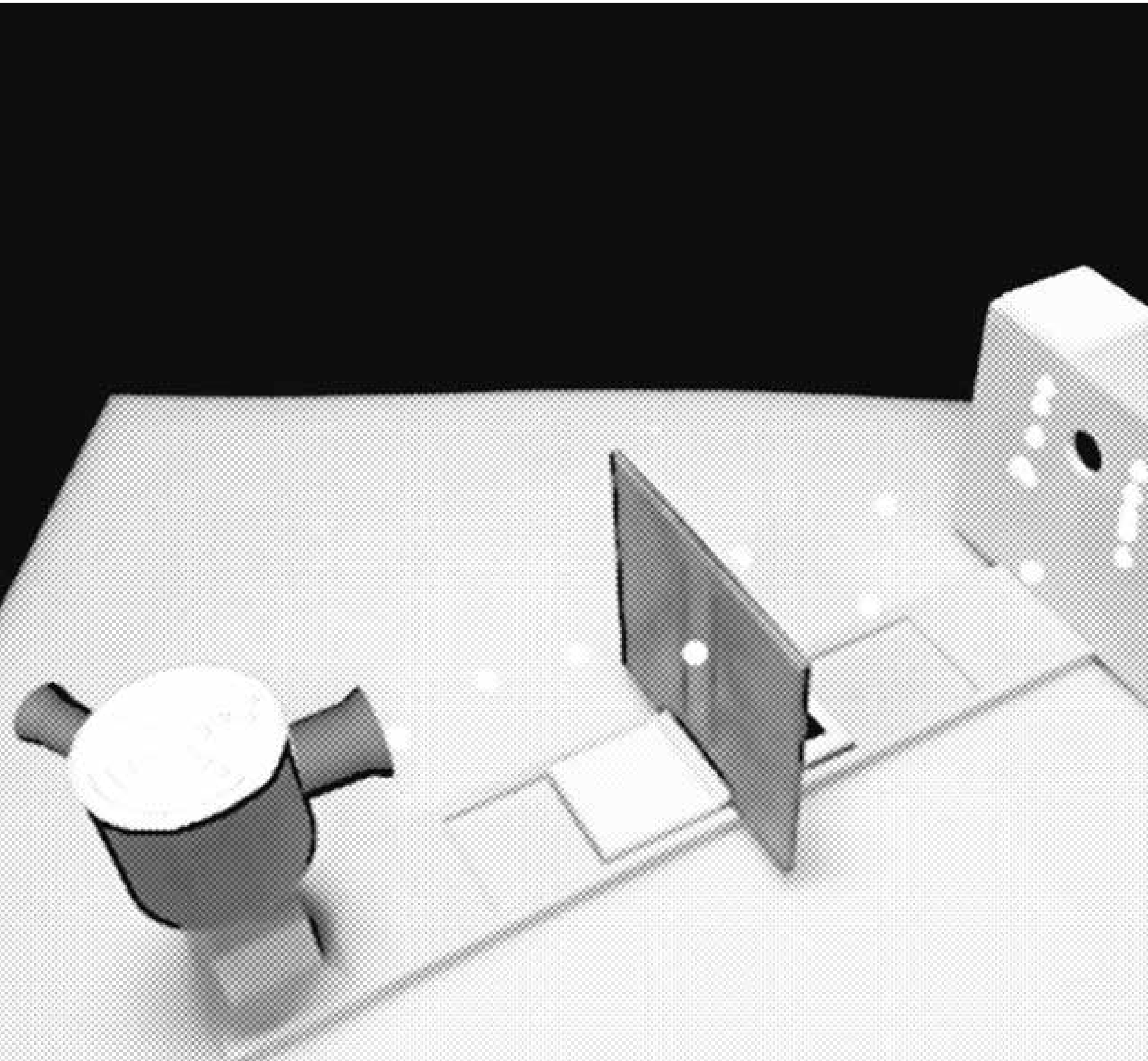




16 / Flat Wing

11 / Fan

3. SCeTGo pedagogical approach



3.1 Introduction

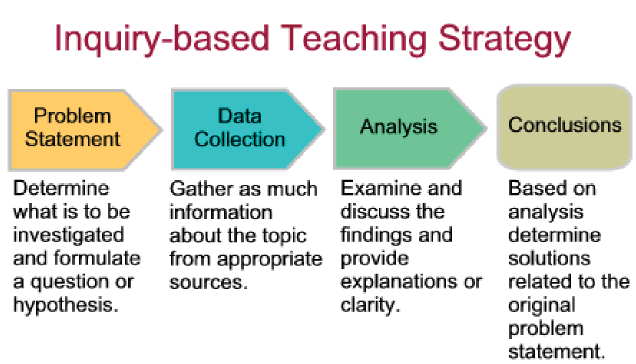
SCeTGo aims at improving science education, enhancing scientific literacy and students' critical thinking skills, involving various learning environments (schools, universities, science centers) and recognising the diversity of personal learning styles and behaviours in different contexts and applications. Furthermore, SCeTGO claims to promote young people's interest in science through the introduction of its informal character in formal educational environments, which motivates students of both genders.

The theoretical framework underpinning SCeTGo is grounded on and structured around two important axes, namely:

- Inquiry-based and creative problem based approaches
- Augmented Reality technology and its integration with miniature exhibits.

3.2 Inquiry Based Science Education

The Rocard Report for European Commission recommends renewal of schools' science-teaching pedagogy by "introduction of inquiry based approaches in schools" (Rocard, 2007: 22). Inquiry Based Science Education (IBSE) is rooted in the scientific method of investigating phenomenon in a structured and methodical manner. Related to teaching and learning, it is an information-processing model that allows students to discover meaning and relevance to information through a series of steps that lead to a conclusion or reflection on the newly attained knowledge. The report also suggests that IBSE can provide increased opportunities for cooperation between actors in the formal and informal arenas.



In most cases of IBSE, teachers use a "guided inquiry" method to facilitate the learning experience and structure the inquiry around specific goals of instruction. The benefits of inquiry-based learning include the development of critical thinking, creative thinking, and problem solving. The process from a teacher's point of view is described in figure 1.

Figure 1: *Teacher perspective of inquiry-based learning (http://www.worksheetlibrary.com/teachingtips/inquiry.html)*

Further, Levy (2009) suggests a model that contrasts teaching/learning strategies on a matrix (Figure 2).

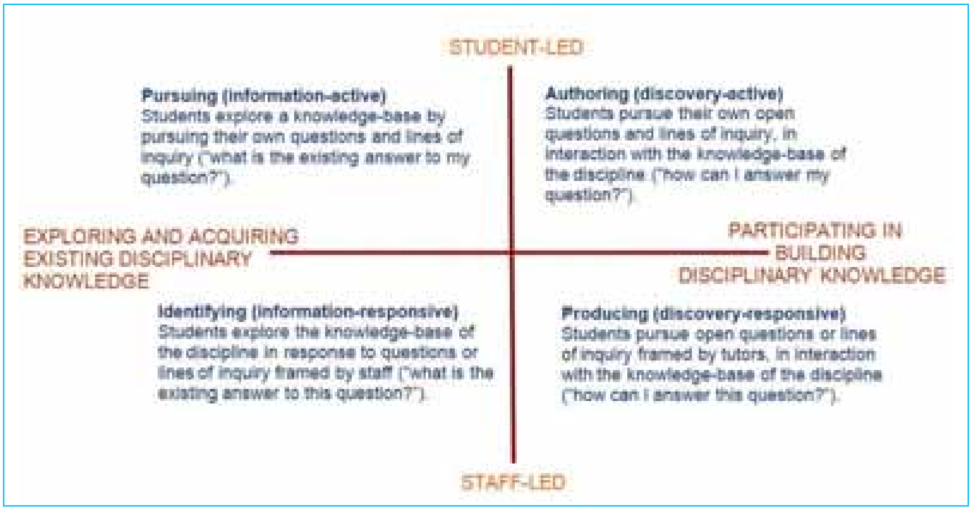


Figure 2: *Inquiry-based Learning: Conceptions and Approaches (Levy, 2009)*

Levy's framework describes inquiry-based learning in terms of whether the tasks are allocated by the teacher (staff-led) or whether the learners formulate questions themselves (student-led). As learners develop skills of scientific inquiry they should move towards student-led inquiry. Within SCeTGo teachers can encourage learners to compose questions that can be answered either by using the software or by further research.

Building on the work of Bruner (1962), Taba (1963) we outline a scenario for discovery-based, or inquiry-based learning:

1. Confront learners with a problem that initially baffles them.
2. Prompt to utilise previously acquired knowledge and perception to recognise ways to tackle the problem.
3. When learners have solved this problem, present them with another one in which they can demonstrate the principles they have now acquired.

SCeTGo fits into this scenario very well. We ask hard questions. Why do planes fly? Why does a fire engine sound different when it's moving towards or away from you?

For fostering engagement with SCeTGo miniatures the IBSE scenario typically include the following elements (not exclusively in this order):

- Setting the challenge
- Recalling prior learning
- Collaboration
- Making and testing hypotheses
- Teacher intervention/prompting
- Feedback
- Assessment

The first step in any inquiry is the formulation of a question or set of questions related to the topic of inquiry. The question can be posed by the teacher or by the pupil(s). Sometimes the question is referred to a hypothesis or a problem statement.

Once a question is posed, pupils are encouraged to investigate the topic by gathering information from sources that either the teacher provides or within learning resources or tools that are readily available to the pupils.

When enough information related to the topic of inquiry is gathered, it is organized in categories or outlined by highlighting the important information relative to the topic. This helps the students to make connections with new learning and prior learning.

The information is discussed and analyzed for further understanding. The teacher can direct the discussion and highlight the implications that arise from the investigation and show how it relates to the solution of the problem.

Conclusions are made and related back to the original question. Student reflections are encouraged and serve as a way to relate back to the inquiry and retrace the steps that led to the conclusion. This also serves to reinforce the model so that pupils can repeat the process in any problem-solving situation.

A more recent analysis divides inquiry-based learning into two types (see CILASS, 2008):

- finding out information from existing knowledge, the “information frame”
- building and evaluating new knowledge, the “discovery frame”.

Both of these frames can be relevant to SCeTGo but the initial focus is on the discovery frame. The learners can be encouraged to be real scientists and to find out something using the miniatures and the AR that they did not know before. They can then judge whether this fits in with their pre-existing perceptions, for example, "objects do not roll uphill" or "light is a wave."

In SCeTGo the information frame would normally come into play after the encounter with the miniature, if the intention is to follow up the activities with further research into existing disciplinary knowledge. It is important that the learners have not studied all of the theory, appropriate to their level, behind the miniatures before they see them, so that there are still opportunities to learn by discovery. For example, younger learners may have learned about the observable properties of sound but they may not know that it travels in waves. So one challenge for them would be to say what they thought the lines represented on the mini-fire truck AR.

A possible exception to this general principle is that learners could find out beforehand how scientists work, for example how they make incremental changes and how they formulate hypotheses and then test them. This would be a useful strategy if the learners are not familiar with scientific and laboratory techniques.

3.3 Augmented Reality and Learning from overlays

Augmented Reality is a term describing those technologies that allow the real-time mixture between computer-generated digital content and the real world (Haller et al., 2007). AR can also be defined as being an overlay or superimposing of digital data visualised on top of the real view of the surrounding environment.

Based on the preliminary findings of AR research and projects in education, such as Construct3D[1], HIT Lab NZ[2], learnAR[3], AR Volcano Kiosk exhibit[4], etc. the impact of AR in education can be summarized as follows:

- AR technology supports inquiry-based and collaborative learning.
- AR technology can add excitement and entertainment to the learning activities, thus increasing motivation among participants of the learning experience.
- AR technology is well suited for demonstrating spatial and temporal concepts and it provides advantages over traditional media

1 *http://www.ims.tuwien.ac.at/research/construct3d/*
2 *http://www.hitlabnz.org/wiki/Home*
3 *http://learnar.org/*
4 *http://www.hitlabnz.org/wiki/AR_Volcano*

AR has the possibility to offer contextual benefits, being able to compare different objects, which also can be in context of the real world. A user can, for example, hold different models in his/her hands and compare them.

AR could be used as a ground for supporting constructivism. It can allow students to explore information about the surrounding environment at his/her own pace, and to construct his/her own knowledge.

Overall, Augmented Reality provides powerful contextual, situated learning and explorative and discovery learning experiences that may help to connect "new layers" of information in the real world. From a different perspective, the combination of physical and computational media allows moving the interaction beyond the computer screen and offers new opportunities for interaction between the virtual and the real world in novel ways. One major benefit of doing this is to provide different ways of thinking about the world from interacting solely with digital representations or solely with the physical world. The purpose of providing this kind of multiple representation is to provide a link between the abstract data and the physical activity of collecting it, in a way that enables learners to reflect on how the different combinations of the variables they have been measuring or aspects they are investigating affect these latest processes. The visualizations of these phenomena also provide a sense of personal relationship with the data. This can facilitate learners' ability to recall what happened for the various projected data points connected to their experimentation and observation. Having a more intimate relationship with the abstract data, in the sense of knowing how they were physically created, may trigger strong associated concepts related to complex learning (Milrad et al., 2002).

The main advantage of the AR, which is one of the basic innovative aspects of SCeTGo is that invisible information about a phenomenon is visualised to the students.

According to the information theory (Bateson, 2000), from the point of view of learning about certain phenomena, the learner should observe change and reflect on it in order to understand what is happening. Bateson defined information as "a difference which makes a difference." In order to make AR to be of value, the overlay has to be strong in showing the "difference", otherwise we are just contributing to confusion. In fact AR should be amplifying the difference. The pedagogy of AR (which we are pioneering) needs to be clear in delivering the advantage. This advantage comes not just from showing what cannot be seen, but making sure that when the invisible is made visible it adds value and not confusion.

The challenge for the scenario design is:

1. Adding AR should do something that is difficult to do without AR
2. AR is about adding things you cannot see - it may be measurements, vectors/scalars, particles, waves, etc.

3. Teachers should not have to spend more time explaining the AR overlay than they would on the phenomenon itself
4. The AR should be truly explanatory or preferably the AR contributes to an investigation of a phenomenon, which is important for Inquiry-Based Science Education (IBSE).
5. Teachers should not have to tell students what the AR is showing and apologise for where it is confusing. In general, misconceptions could be expected but such misconceptions should not be a result of the AR.
6. AR should amplify the differences that make the phenomenon understandable.
7. AR experiments should be flexible enough to allow usage in different scenarios and in different moments of the lesson/learning process

We describe some of the ways that SCeTGo could do this in the tables in the Appendix.

3.4 Important Pedagogical Factors and Constraints

In addition to the characteristics of IBSE we have outlined we can simplify the order of activity in IBSE:

- Question(s) related to the topic of inquiry are explored (problem statement).
- This is followed by an investigation and gathering of information related to the question (data collection).
- This followed by a continuing with a discussion of findings (analysis).
- Then there is a process of reflection on what was learned (implications/conclusions).

Thus the first step in any inquiry is the formulation of a question or set of questions related to the topic of inquiry. The question can be posed by the teacher or by the learner(s). Sometimes the question is referred to as a hypothesis or a problem statement.

The challenge for the teacher is to identify a challenge suited to the age group and ability of the learners, and to introduce it in such a way as to give them enough background information, but not so much that there is no issue left to investigate.

The way to solve the challenge should not be initially obvious to the learners, but they should already have in place the mental tools to tackle it. The main role of the teacher will be in encouraging the learners to recall the skills and knowledge they need whilst leaving plenty of scope for discovering new knowledge. For example younger learners could practice the vocabulary they use to describe sound, for example loud, quiet, pitch, note, high, low. For the Young's double slit miniature younger learners could describe what they already know about waves on the sea shore, and older science students could recap on what they have learned about the properties of waves and particles. The objective is to recognise patterns that can be used to tackle the challenge. The recall could be prompted by, for example, a quiz or a short video that the group could discuss.

In each activity there are two new situations. One is the science and the other is the technology, the AR. The learners will need to master the AR before they can tackle the scientific challenges. This is a scientific inquiry in itself. In some situations it may be useful to have a group discussion what the learners prior knowledge leads them to expect when they start to interact with the miniature.

The learners are likely to be able to extrapolate their existing knowledge of ICT skills to understand the AR fairly quickly but they will probably need some practise before they can manipulate the miniatures effectively. With each successive miniature they use they will have an increased body of prior knowledge.

Once a question is posed, students are encouraged to investigate the topic by gathering information from sources that either the teacher provides or from learning resources or tools that are readily available to them. When enough information related to the topic of inquiry is gathered, it is organized in categories or outlined by highlighting the important information relative to the topic. This helps the students to make connections with new learning and prior learning.

The investigation itself will consist of a cycle of making and testing hypotheses, following an experiential learning cycle, first suggested by Dewey and developed by Kolb (Petty, 2004):

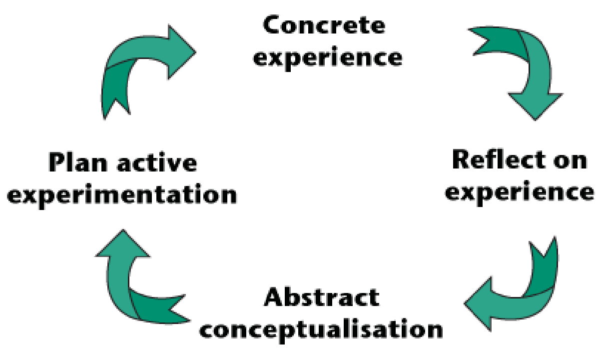


Figure 3: *Inquiry cycle*

At first the cycles will be very brief, and will consist of hypothesising what the miniature and screen will do in different alignments, and testing this out. Once this has been achieved the group can turn its attention to the main challenge it has been presented with.

An important principle of scientific investigation is that only one change is made at a time. It is likely that untrained learners will make multiple changes, for example the rate of “killing” creatures, the total time and the background in the evolution scenario.

At first the learners can be allowed to make these “mistakes” in order to learn that, ultimately, a methodical approach is needed, but they may eventually need prompting. If all or most of the miniatures are explored by each group in one class, or series of classes, then this is an excellent opportunity for the learners to improve their techniques with each exhibit they visit and to apply their newly-learned skills of scientific investigation to new situations.

The learners may need to be encouraged to stop to reflect on what they have learned, to fit that into their mental model of the situation (adjusting it if relevant) and deciding whether they have completed their challenge, and if not what to do next. The skill here in classroom organisation is to achieve this but without imposing so much structure on it that the whole process ceases to be playful and exploratory.

The information is discussed and analyzed for further understanding. The teacher can direct the discussion and highlight the implications that arise from the investigation and show how it relates to the solution of the problem.

In SCeTGo the most likely classroom organisation will be that groups of up to six learners working with one miniature at a time. Interpersonal relations are precursors, and necessary conditions, for the emergence of individual understanding. Learners first share their experience with others, before they become able to master and understand them for themselves.

Obviously teachers will apply their normal strategies in their classrooms to encourage appropriate behaviour and productive interactions within the groups, so this will not be elaborated further.

However, it is important to note that in the constructivist model the plausibility of guesses should be recognised, providing that the learners are being scientific in their approach. Learners’ prior experience may have led them to believe that the objective is to get the “right” answer as quickly as possible rather than to spend time perfecting models and testing hypotheses (Wood et al., 1978). Learners are often skilled at getting the teacher to give them clues as to what the expected answer is. There is a fine distinction between correcting student misconceptions and “giving the game away”. Often what is needed in these situations is reassurance that it is acceptable to be doing something different from the other groups with a particular miniature.

There may be some circumstances in which required to redirect the learners to the formal curriculum. In these cases, in the final whole-class discussion in which the groups compare their findings, the teacher will be able to acknowledge scientific thinking as well as correct solutions.

Obviously intervention is needed if a group is not making any progress. The teacher needs supply of questions that stimulate higher order thinking, and possibly other resources such as different equipment (for example ping pong balls on strings to "discover" Bernoulli's principle).

At the other end of the spectrum if learners solve a problem quickly the teacher needs ideas for further work. It is possible someone might solve the uphill roller puzzle very quickly. If so they could explain it to the rest of the group, and then they could deduce the conditions needed for an uphill roller to work. Depending on the age and ability of the learners this could be descriptive or mathematical.

Good feedback is one of the key tenets of constructivism. There are five opportunities for feedback in the wider SCeTGo scenario:

1. At the recalling prior knowledge stage, to confirm that learners have the background knowledge and skills they need in order to start the inquiry
2. During the inquiry, as a prompt, to redirect learners if necessary
3. At the end of the enquiry, to comment on the conclusions the learners have drawn
4. At the end of the class, as a class discussion to share results and observations
5. Following further research into the topic

According to Black and Wiliam (1998), research shows very clearly the conditions under which feedback is successful. For example when feedback focuses on what learners need to do to improve, and, in particular, how to go about it, then you get very large impacts on learner achievement. So the challenge for teachers is to take these very broad principles and work out what it means for SCeTGo. Critically important are the dialogues that take place whilst the miniatures are used. This is key to learning.

Some of this feedback can be mediated by paper or digital resources, for example answers to quizzes or videos. However the important role of the teacher is as an observer / guide / feedback-giver and not answer-giver. In the earlier stages the feedback can be in the form of questions, to encourage learners to find their own solutions. Ideally most of the feedback should be face-to-face, but in a busy classroom where several groups of learners are working on different activities this is not always feasible.

Conclusions are made and related back to the original question. Student reflections are encouraged and serve as a way to relate back to the inquiry and retrace the steps that led to the conclusion. This also serves to reinforce the model so that students can repeat the process in any problem-solving situation.

3.5 References

Bateson, G. (2000). *Steps to an Ecology of Mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology,* University Of Chicago Press

Black, P. & Wiliam, D. (1998). "Inside the black box: Raising standards through classroom assessment". *Phi Delta Kappan*, 80(2), 148, 139.

Bruner, J. (1961). "The Act of Discovery". *Harvard Educational Review*, 31, 21-32.

Bruner, J. (1962). *On Knowing: Essays for the Left Hand*, Cambridge: Harvard University Press.

CILASS (2008). "Inquiry-based learning: a conceptual framework", Centre for Inquiry-based Learning in the Arts and Social Sciences, University of Sheffield. Available at: http://www.sheffield.ac.uk/content/1/c6/07/93/44/Microsoft%20Word%20-%20CILASS%20IBL%20Conceptual%20Framework%20_Version%202_.pdf [Accessed May 10, 2010].

Haller, M., Thomas, B. & Billinghurst, M. eds. (2007). *Emerging technologies of augmented reality: interfaces and design*, Hershey: Idea Group Pub.

Levy, P., (2009). "Inquiry-based learning: a conceptual framework", Centre for Inquiry-based Learning in the Arts and Social Sciences, University of Sheffield. Available at: http://www.shef.ac.uk/content/1/c6/09/37/83/CILASS IBL Framework (Version 4).doc

Milrad, M., Spector, J.M., & Davidsen, P. I. (2002). "Model Facilitated Learning". Book chapter in S. Naidu (Ed.), *Learning and Teaching with Technology*: Principles and Practices, Kogan Page Publishers, London, UK and Sterling, VA, USA, pp 13-27.

Petty, G. (2004). "*Teaching Today - A Practical Guide*" 3rd ed., Cheltenham: Nelson Thornes.

Rocard, M. (2007). "*Science Education NOW: A renewed Pedagogy for the Future of Europe"*, European Commission, Directorate-General for Research, Information and Communication Unit. Brussels. Available at: http://ec.europa.eu/research/science-society/document_library/pdf_06/report-rocard-on-science-education_en.pdf

Taba, H. (1963). "Learning by Discovery: Psychological and Educational Rationale". *The Elementary School Journal*, 63(6), 308-316.

Wood, J. et al. (1978). "Spreadsheets". *Micromath*, 3(2). Available at: http://www.atm.org.uk/journal/micromath/mm032wood.pdf [Accessed May 17, 2010].

3.6 Appendix

Mini-wing (wing dynamics)

Real world difference[1]	Physics difference[2]	SCeTGo design	SCeTGo difference *These are design considerations in implementation*	Student perception specific to the AR implementation
the plane goes up i.e. flies	Air pressure above the wing is less than below the wing producing upthrust.	We show changes in the direction of the flow of air by representing airflow as lines. We clearly need to show a difference in speed of airflow and that needs strong exaggeration. As the fan moves towards the wing the airflow increases. Arrows whose length varies and direction changes show drag and uplift .	Lengths of arrows change Direction of lines change Frequency of arrows on flow lines increase.	The student clearly has to be aware of what it is the overlay is actually showing, etc. and if it is showing a variable (like velocity of airflow) then that has to be emphasised.

[1] *Real World Difference is what the everyday observer perceives without asking scientific questions.*
[2] *Physics Difference is the explanation that a good science teacher would use to explain a phenomenon.*

Mini-cooler and heater (kinetic theory of gases)

Real world difference	*Physics difference*	*SCeTGo design*	*SCeTGo difference* *These are design considerations in implementation*	*Student perception specific to the AR implementation*
Hot and cold are subjective appreciations of temperature. We experience the air as having different temperatures.	Temperature of a gas is a function of the kinetic energy of the gas molecules. The higher the velocity of the molecule the higher the temperature. This energy is a function of the square of the velocity. $pV = NkT$	We make visible a fixed number of spheres that represent molecules within a specific volume. We measure temperature in three environments. The speed of the molecules changes in the three environments. This is reflected on the on-screen temperature and graph.	Perceiving the changes in speed is crucial. Should there be a countable number of molecules? How we have students appreciate the control of variables?	Students have to appreciate that the speed of the spheres represents the speed of particles. Students have to recognize that at different temperatures have different speeds. Certain aspects of the phenomenon, mainly relating to the density of gas at different temperatures, may cause confusion.

Mini-double slit (quantum mechanics)

Real world difference	Physics difference	SCeTGo design	SCeTGo difference These are design considerations in implementation	Student perception specific to the AR implementation
When light (or any electromagnetic source) or an electron source is projected onto a screen through double slits an interference pattern is detected on a detection screen. This phenomenon seems to hold when describing light or electrons as waves - emulating what is observed when water or sound waves are subjected to a similar set up. However it obviously holds true even if we believe light or electrons to be particles. Except, if we have a detector to detect particles, the phenomenon does not occur, i.e. once we decide that radiation or electrons behave as particles and detect them as such the phenomenon is not observed.	The phenomenon is described by the equation: $\frac{\tan\alpha = \sin(\frac{\beta}{2})}{\tan\chi}$ where λ is the wavelength of the light, d is the separation of the slits, the distance between A and B in the diagram to the right n is the order of maximum observed (central maximum is n = 0), x is the distance between the bands of light and the central maximum (also called fringe distance), and L is the distance from the slits to the screen centre point.	We provide a virtual gun firing particles, waves or electrons/ photons through one or two slits onto a screen. The distance of the slits from the gun can be varied. The pattern appearing on the screen is shown. There are three different kinds of animation overlays. The overlay's result will vary dependent of the spacing of the slits used. This will change the pattern on the screen.	As Waves, the overlay will replicate wave tanks and wave tank interference patterns. As particles, as discrete blobs are fired at the slits. These will build up interference patterns with distribution of "blob hits". In electron/ photon mode particles are fired but an interference pattern appears on the screen.	The main limitation in perception is that ripples/waves are normally viewed from above. To observe the particle behaviour we would need to view from a different angle. The animation of particles gives an idea of time lapse and the pattern builds up. For waves there is a continuous show of the interference phenomena (as happens in real life).

Mini-fire truck (the Doppler effect)

Real world difference	Physics difference	SCeTGo design	SCeTGo difference *These are design considerations in implementation*	Student perception specific to the AR implementation
As a fire engine approaches, the pitch of the notes of the siren seems higher than it would be for a static vehicle. As it moves away it gets less. This is compounded by changes in volume one might expect. However the change in note is perceived as the vehicle passes. A phenomenon is also noticed when the source is stationary and the observer is moving; and any combination of movements of the two. In the real world, but not experienced by people or observable in a school or museum, are shifts in the light spectrum in large astronomical objects within an expanding universe.	When an object that is a source of a wave and an observer are moving relative to each other there is a change in wavelength of the wave is perceived by the observer. With sound this appears as change in pitch; in light, at astronomical speeds, this appears as a change in the spectrum.	We have a model fire engine as the source of waves and a model sound detector/ observer. In a static situation wave propagation is perceived as concentric circles of different intensity of red – these may be explained as the wave fronts/peaks. When the source moves the wave fronts appear to be much closer together in the direction of travel. This makes the circles appear as ellipses.	There are two and possibly three significant differences with the sound wave experiment; changes in pitch, the change in the shapes of the patterns and colours of the propagation of sound changing the apparent wave propagation in the direction of travel. We might consider changing the volume.	The crucial understanding comes from knowing the way we are representing the propagation and speed of sound waves, i.e. the slower sound waves are moving the closer they are. The important difference for the student to observe is simultaneously realising that the change in frequency of the sound source and the apparent asymmetric propagation of the sound “circles”. This is not so apparent when the observer moves. This is difficult to represent.

4. Scenarios of Use

4.1 Introduction

As seen in the previous Chapter, Inquiry Based Teaching is a teaching strategy where teachers facilitate student-centered learning and research, acting more as a colleague and guide rather than the dispenser of knowledge. The central aim is to develop students' intellectual autonomy. Adopting this strategy can become a powerful tool for teachers who want to develop students' capacity to think for themselves. For teachers who want to adapt situations for individual needs, it is also a good way to understand how a specific student thinks about a particular problem.

In this section, we present the general structure of an educational learning activity template (Figure 4.1) that was used for designing scenarios for each miniature of the SCeTGo system that implemented the Inquiry Based Teaching methodology both in formal and informal educational settings.

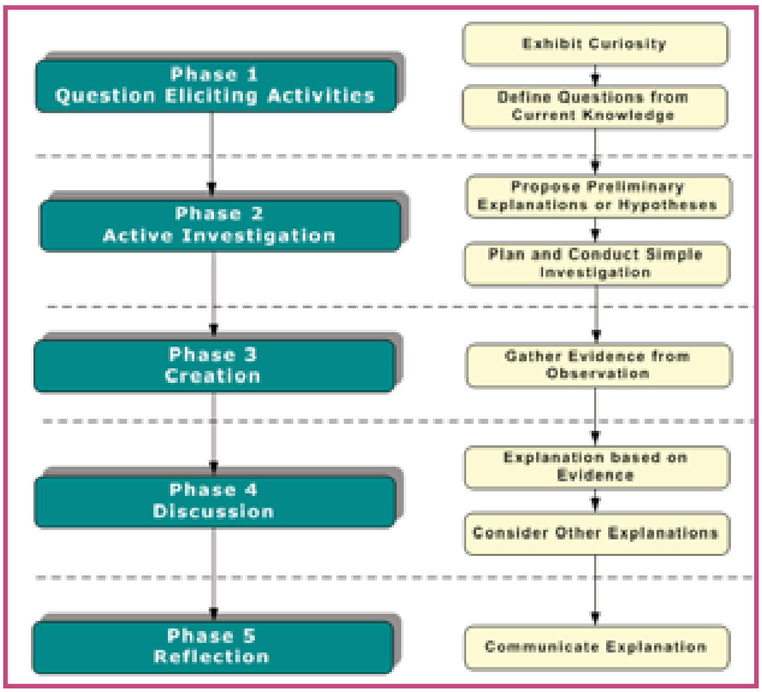


Figure 4.1 *Inquiry-based Science Education model for designing learning scenarios*

Over the next pages of this chapter, five indicative scenarios are presented, each one supporting a different miniature exhibit of the SCeTGo augmented reality system.

4.2 Educational Scenarios

Scenario A
Mini-fire truck (the Doppler effect)

Description:

The students make a short study of sound using Science Center To Go The Doppler Effect exhibit. The demonstration of the experiment is based on advanced visualization techniques.

Learning Time: more than two hours

Age Range: 15-18

Guidance for Preparation
Theory

Christian Doppler, (1803-1853), Austrian physicist who first described how the observed frequency of light and sound waves is affected by the relative motion of the source and the detector. This phenomenon became known as the Doppler effect.

Educated at the Polytechnical Institute in Vienna, Doppler became director of the Physical Institute and professor of experimental physics of the University of Vienna in 1850. His earliest writings were on mathematics, but in 1842 he published Über das farbige Licht der Doppelsterne ("Concerning the Coloured Light of Double Stars"), which contained his first statement of the Doppler effect. He theorized that since the pitch of sound from a moving source varies for a stationary observer, the colour of the light from a star should alter, according to the star's velocity relative to Earth.

Reference: Encyclopedia Britannica. Retrieved from *http://www.britannica.com/EBchecked/topic/169325/Christian-Doppler*

Experimental Set-Up

The demonstration/experimentation includes three main experimental set-ups. The Doppler effect is demonstrated by three different experimental sep-ups: 1) by simple equipment, 2) by the Doppler effect Miniature Exhibit that has been developed in the framework of the Science Center to Go project, 3) by Vernier Doppler rocket application (optional). You will need:

- buzzer, tape, battery, string
- Vernier Doppler rocket (optional)
- Science Center to Go AR Software
- Science Centre to Go Doppler effect Miniature Exhibit
- PC and projector
- Access to the Internet

Flying Fox overhead, Kahunapule Michael Johnson, Flickr.com (Creative Commons).

Exhibit Curiocity

Have a look for this Nature Video Channel's presentation of Bat's senses. This video can be presented for students to discuss about bats' ability to flight in darkness. How do bats navigate at night? What senses do they need? How would you explain this ability?

Further reading

- Wild Detectives: Bats by Night (National Geographic Channel)
- Bats and Doppler effect (The Journal of Experimental Biology)

Define questions from current knowledge

Here are some discussion questions for students:

- Imagine that you are standing on the border of the road. A motorbike passes. What kind of sound does it make before and after passing?
- In which other situations have you heard same kind of phenomenon?

On the next phase teacher shows the following videos of the same phenomenon, the Doppler effect:

- Doppler & trumpet players • Doppler & car horn • Doppler & passing train

Questions:

- Does the volume change when the train/car passes?
- Does the pitch change when the train/car passes?

Passing motorbike, Frank Kehren, Flickr.com

Active Investigation

Propose preliminary explanations or hypotheses

The teacher asks the students to present their ideas and to make some initial hypothesis about the phenomenon:

- What is sound? What is its nature?
- How can you hear sounds?
- What is different with different sounds?
- How does sound move?
- What changes when the source of sound moves?

Model of sound:

Sound is a pressure wave, which spreads in the air in three dimensions (spherical wave). The sound moves with same speed to every direction.

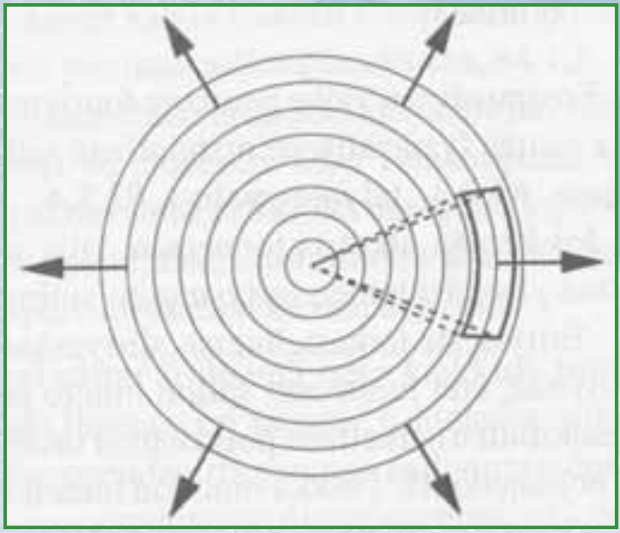
- Simple Spherical Wave (online wave animation)

Common Students' Misconception:

The most common misconception is:

- it is only the volume that changes when the source of sound passes the listener

After students have made their predictions the teacher proceeds to the next phase (investigation)



Supporting material

Plan and conduct simple investigation

Buzzer and Doppler

Before the primary experiment the following little experiment can be done either at school or at home:

What do you need?

• buzzer • tape • battery • string

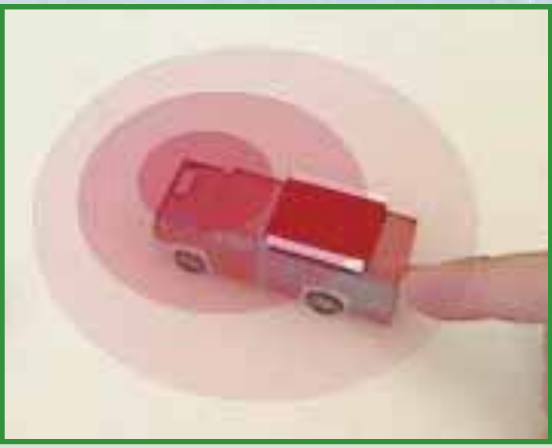
What to do?

Connect a buzzer to a battery and tape it carefully.
Rotate the packet with a string overhead like a hammer thrower.

Observation 1: The pitch varies in phase with rotating the buzzer.
Observation 2: The sound is higher when the buzzer closes the listener and lower when it recedes.

Other simple investigations

Other possibilities in this phase are to investigate the phenomenon by watching the video of passing car or investigating the phenomenon by a Doppler rocket. Show videos of: • Passing car • Doppler rocket



Gather evidence from observation

The teacher is using the Doppler effect Miniature exhibit, following the guidelines that are provided with the Tool-Box.

1. Do experiments by mini-fire truck.
2. Compare

- Different pitches (frequencies) and volumes of the sound: What do you hear when the truck passes? Is it the volume or pitch of the sound that change?
- Different shapes of the spherical wave when the truck is in place or moving: How do the original spherical wave transform when the truck moves?
- Different frequencies measured

3. Draw the minifire-truck in different situations: • in place • moving (Include also the wave-front to your drawings.)

Discussion

Explanation based on evidence

Sound is a pressure wave, which spreads in the air in three dimensions (spherical wave). The sound moves with same speed to every direction.

The source of sound in place

The reason for hearing the Doppler effect is the transformation of the spherical wave of the sound. When the source of the sound is not moving but in place, the sound is heard similarly in every direction. In this case every wave length is equal. The spherical wave is made visible by the mini-fire truck. So, it is possible to compare the length of wave. Respectively, sound of the mini-fire truck is able to listen from different directions. Also the frequency can be measured.

The source of sound moves

When the source of the sound moves, the form of the spherical wave transforms: in front of the source of the sound the wave-fronts are closer each other than behind the object. This means that also the wave length is different in these places. Short wavelength means high pitch (high frequency); respectively long wavelength means low pitch (low frequency).

The transformation of the spherical wave is able to be seen by the mini-fire truck experiment. Also the different pitches of the sound can be heard. Teacher shows videos on the following topics:

• Doppler effect - source in motion • Animation: Doppler effect • The Doppler Effect and Sonic Booms

Galaxy, NASA, Wikipedia (Wikimedia Commons).

Consider other explanations

Teacher expands students' explanations by introducing other fields of phenomena where the similar kind of Doppler effect takes place.

Doppler effect in water

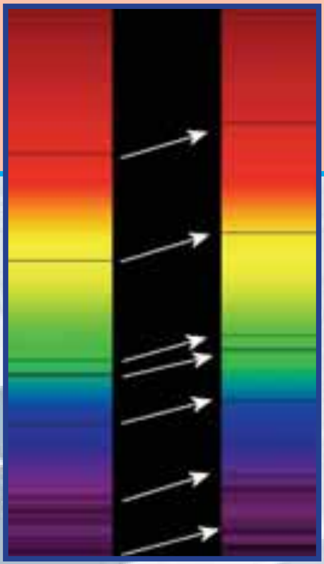
Doppler effect can be observed also in water.

Light and Doppler effect

You can experience the Doppler effect with all types of waves. Light is wave motion of the electromagnetic field and the frequency of light determines the colours we see. White light is a mixture of colours - that when we split it gives the rainbow colours from dark blues to red.

The spectrum of light from galaxies moving away from us seems to have shifted towards the red end of the spectrum. The spectrum of light from galaxies moving towards us seems to have moved towards the blue end of the spectrum. Astronomers use these measurements to work out how fast the universe is expanding. They call it the Red shift and the Blue shift. Educational videos on related topics are shown in the classroom:

- Discussing about red shift and expanding universe
- Animation of redshiting and blueshifting
- Animation: Galactic redshift



Picture 2: Duckling in motion, GDL Studio, Greg Lavine, Flickr.com (Creative commons).

Redshift, Xorx, Wikipedia (Creative Commons):

Reflection

Communicate explanation

The students should report on the realized activities. The will need to prepare a report that includes the rational of the experiment, the initial design of the experimentation, the experimental set-up, the realization of the process, the analysis of the findings and a detailed discussion on the results. Students could work in groups, prepare their reports and then present them in the classroom.

Follow-up Activities

Advanced studying: expanding the field of phenomenon

After using the Doppler effect Miniature exhibit the field of Doppler effect is expanded by the following discussions:

- discussing about different situations:
    - source of sound in place
    - source of sound moving
    - source of sound moves as fast as speed of sound (v = c)
    - source of sound moves faster than sound (v > c), so called shock wave is formed
    - calculating frequency of sound:

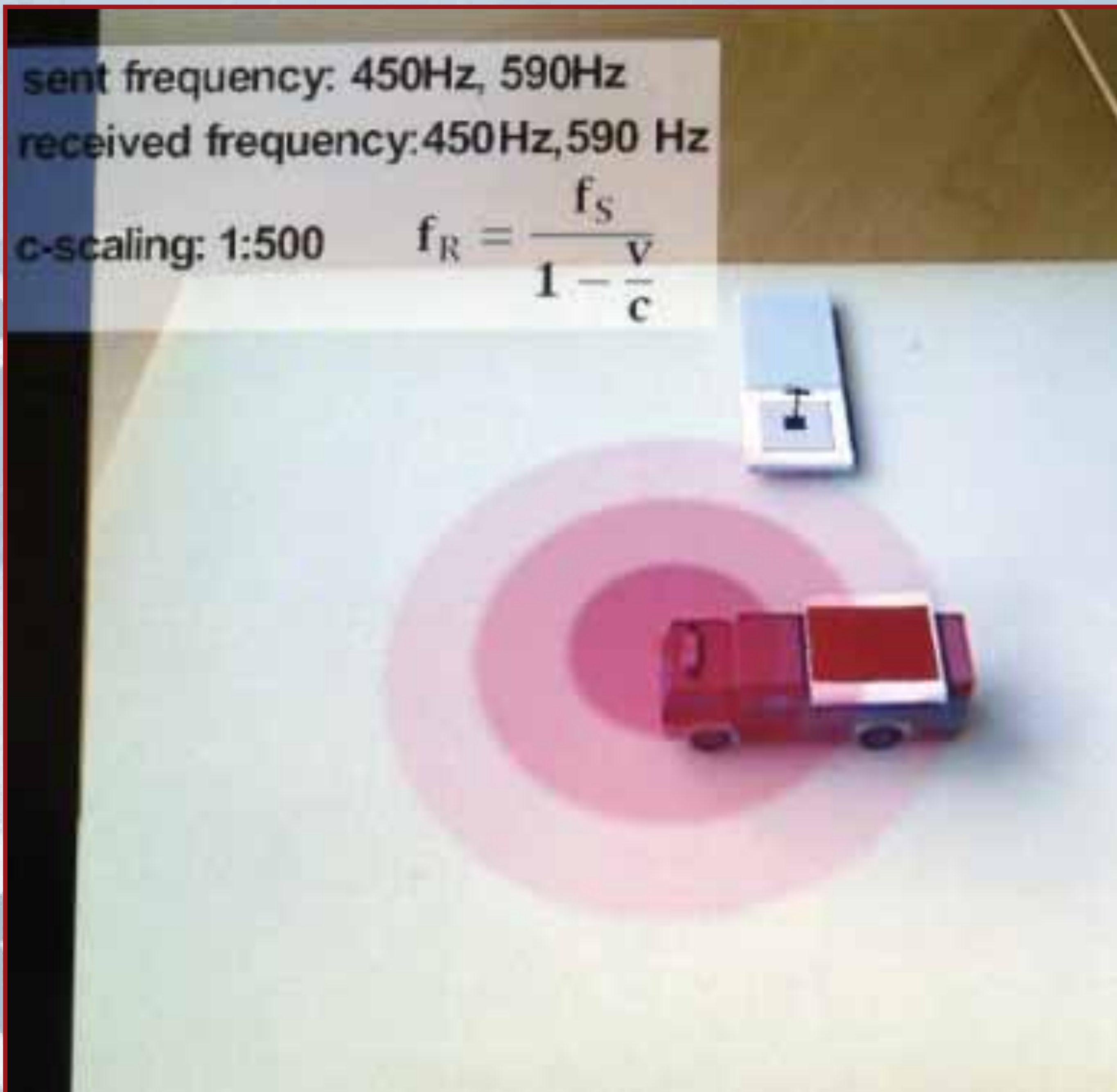
$$f(heard) = \frac{c}{c \pm v} f$$

- calculating detected frequencies
- discussing about principle of Doppler radar

Understanding test

For the assessment of the proposed activities a conceptual understanding test is proposed to be used as data collection tools.

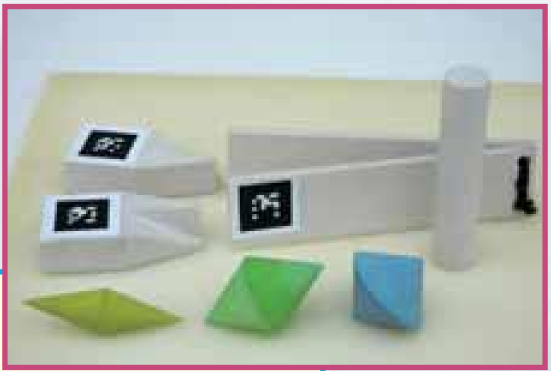
Doppler radar for measuring the velocity of wind, NOAA Photo Library, Flickr.com (Creative commons).


sent frequency: 450Hz, 590Hz
received frequency:450Hz,590 Hz
c-scaling: 1:500
$f_R = \frac{f_S}{1 - \frac{v}{c}}$

Scenario B
Mini-double cone (classical mechanics)

Description:

The students make a short study of gravity using Science Center To Go Double cone exhibit. The demonstration of the experiment is based on advanced visualization techniques.



Guidance for Preparation
Experimental Set-Up

The demonstration/experimentation includes two main experimental set-ups. The first includes the experimental.

- Material to build self double cone equipmen t or similar commercial one
- Some measure instruments
- Science Center to Go AR Software
- Science Centre to Go Mini Cooler & Heater Exhibit
- PC and projector
- Access to the Internet

The demonstration/experimentation includes two main experimental set-ups. The first includes the experimental set-up for the demonstration of the light interference. This could be easily demonstrated with the use of a laser pointer. The second experimental set-up is based on the use of the Double Cone miniature exhibit that has been developed in the framework of the Science Center to Go project. You will need:

- Double Cone device. Homemade or commercial
- Protractor
- Science Center to Go AR Software
- Science Centre to Go Double Cone Exhibit
- PC and projector
- Access to the Internet

Learning Time: more than two hours

Age Range: 15-18

Exhibit curiosity

The teacher shows to students a video made in Science Centre Heureka. The teacher shows to students a quick presentation using real Uphill Roller. Afterwards, the history of the Uphill Roller is presented. The story gives a good view to notice, that 300 years ago science and common life lived very close to each other. *"The inspiration for this physical device comes from a slightly unusual source: The Proceedings of the Old Bailey from April 18th 1694. The business part of the document ends with a list of the 29 unfortunates and continues to another list; this time of advertisements. Surprising though it may seem, advertisements for anything from quack remedies to religious texts formed an important part of the court proceedings between the 1680s and the 1750s. On April 18th 1694 the second item on the list was an advert for a book:*

Pleasure with Profit: Consisting of Recreations of divers kinds, viz. Numerical, Geometrical,, Mathematical, Astronomical, Arithmetical, Cryptographical, Magnetical, Authentical, Chymical, and Historical. By William Laybourn, Philomathes.

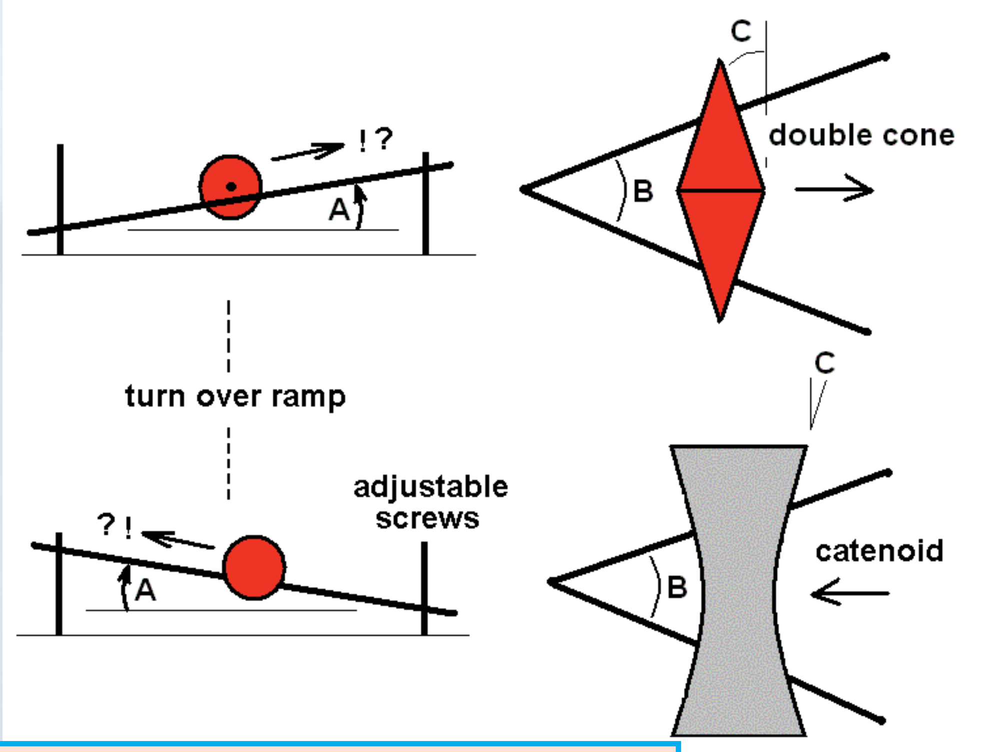
Pages 12 and 13 of the book detail the construction of a double cone and two inclined rails along which the cone can roll - uphill! His final paragraph explains the paradox: even though the cone does ascend the slope, its centre of gravity will actually move downwards, if the experiment is set up in the right way. Although one's senses might be confounded, the law of gravity is not."

Define questions from current knowledge

The first fundamental question is of course:
"Does the Uphill roller really roll uphill and does it disobey the law of gravity?"

It is obvious to the students, that "uphill rolling" is not real phenomenon. This device does not revoke the law of gravity. It is an optical illusion. The centre of mass of the roller does always downwards. In Heureka the Uphill Roller "rolls always uphill", because it is a solid construction. The only thing that a visitor can do is to put a roller or double cone on the tracks. If a visitor puts the roller onto the narrow end of the tracks, it starts to roll and vice a versa on the broad and of the tracks the roller stays where it was put to.

"A good Uphill Roller" has opportunity to vary many things: the angle between the tracks, the slope of the tracks, and use different rollers. Using that kind of device it is easy to notice, that the Uphill Roller does not always roll towards the road end. Sometimes the double cone rolls to the narrow end and sometimes it does not roll at all. So, a crucial question would be: Which are the variables that are responsible for the direction of the rolling? How many are they? Are there any limits in the values of variables?



Propose preliminary explanations or hypotheses

These first steps are suggested to make us think, not to use the uphill roller device.

1. How will affect the variation of the size of double cone?
2. How will affect the variation of the angle between the cones?

- How will behave cylinder instead of double cone?
- How will behave a catenoid (a "negative" double cone)?
- How will behave a ball?

3. How will affect the variation of the angle between the tracks?
4. How will affect the slope of the tracks?

Plan and conduct simple investigation

Students make an uphill roller device using simple and common materials. The main purpose of the investigation is to vary angle of the double cone, between the tracks and the slope of the tracks and see, how the roller behaves. When it goes to the narrow end, when to the broad end and when it stays in place. A ball and a cylinder are also studied similar way and a catenoid, if possible.

The materials needed:

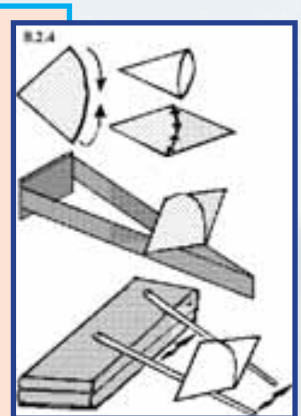
- At least 3 double cones with variable angles. Flexible cardboard is good material to make double cones
- A cylinder and a ball
- 2 long enough (at least 40 cm) rulers or similar as the tracks
- Books or something similar to vary the slope

Finding proper double cones, which are good in size and form, might be difficult. Making them from is rather simple. Here are the instructions:

- Make a circular cone with two heads as follows: Tape together two plastic funnels at their mouths with a smooth connection. Cut out two identical equilateral triangles from cardboard with one side in the shape of an arc. Roll the triangles, beginning at a straight side, then tape together the straight sides to form two circular cones. Rub smooth the bottom of each cone and tape them together.
- Because the top angles of cones Science Centre to Go Double Cone Exhibit are 15, 30 and 45 degrees, the students should make similar double cones. This helps a lot in the next phase.
- It is rather easy mathematical problem to calculate, which kind part from the circle on a cardboard has to cut, if for instance double cone with top angle of 30 degrees is needed. In the calculation is easier get half angle that is 15 degrees.
- Show a video on how to calculate a right angle to the cardboard, when 30 degrees top angle cone is needed.
- If the calculation of the sectors is too difficult to the students, the teacher can give them right angles to the sectors of the partial circle.

Plan and conduct simple investigation

Students will record the values of the variables and the direction of the rolling into the table. It is important to emphasize, that the values of only one variable are changed at the time. For instance, in a first phase the slope of the tracks is kept constant. The student seeks such angle between the tracks that all three double cones roll downwards into the narrow end on tracks. Next the student finds such angle between tracks, those 45 degrees double cone stays on its place, that is do not roll to the narrow nor broad end. Then he/she finds how 30 and 15 degrees double cones behave in the same situation. After that student finds an angle, which keeps 30 degrees double cone on its place and so on.



Gather evidence from observation

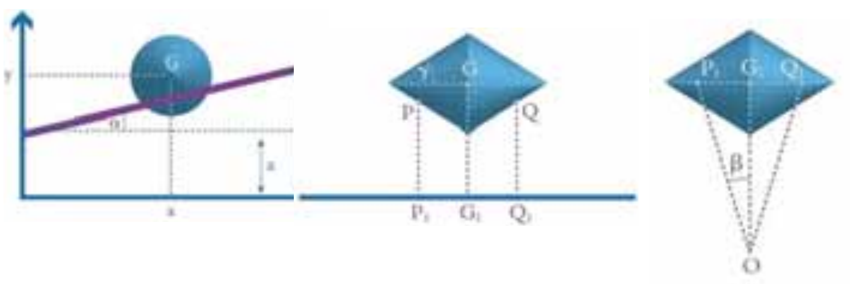
The teacher is using the Double Cone Miniature exhibit, following the guidelines that are provided with the Tool-Box.

The teacher shows, how the system works. Then the students start to study. They try to use the same angles, that they already have studied in Pre Visit -phase. The paper, that they made earlier, should be now present.

Explanation based on evidence

It is easy to notice, that a mathematical conduction to the “uphill rolling” is, that value of the formula is more than 1. But how can it be proved mathematically and physically?

The calculations are not especially difficult, but they are somewhat long. Here is good presentation concerning the mathematics of the double cone or uphill roller.



Supporting material:

Luca, R. D. and Ganci, S. 2011. The uphill roller experiment and a variation on theme. Eur. J. Phys. 32, 101–106. [http://www.osrportal.eu/files/uploads/pathway-objects/double_cone_2.pdf]

Consider other explanations

The cylinder rolls always "downhill", but how about a ball. How does a ball behave on the tracks?

It would be good, if the students can predict the behaviour of the ball before they can try it.

There are always some suspicions, that double cone is some kind fool - among other suspicious things. Or that it is magnetic, and magnets are hidden somewhere inside the double cone. Students should discuss how rational these doubts are.

Communicate explanation

The students should report on the realized activities. The will need to prepare a report that includes the rational of the experiment, the initial design of the experimentation, the experimental set-up, the realization of the process, the analysis of the findings and a detailed discussion on the results. Students could work in groups, prepare their reports and then present them in the classroom.

Scenario C
Mini-wing (wing dynamics)

Description:

The students make a short study of aero dynamics using Science Center To Go Mini Wing exhibit. The demonstration of the experiment is based on advanced visualization techniques.

Guidance for Preparation
Experimental Set-Up

The experimental set-up is based on the use of the Mini Wing miniature exhibit that has been developed in the framework of the Science Center to Go project. You will need:

- Science Center to Go AR Software
- Science Centre to Go Mini Wing Exhibit
- PC and projector
- Access to the Internet

Learning Time: more than two hours

Age Range: 15-18

Exhibit curiosity

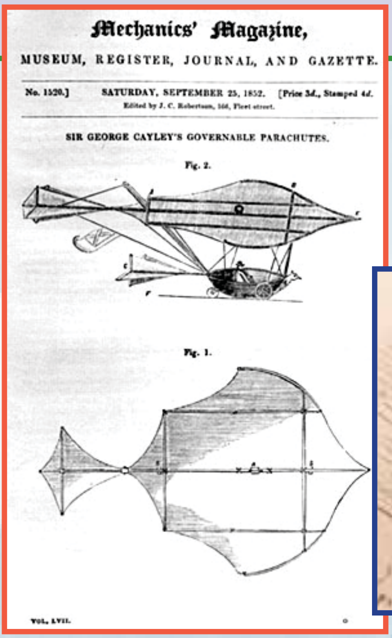
The pathway of wing dynamics is started by discussing different learning situations and objects. Teacher can prepare the discussion by familiarizing himself with the history of aviation.

Following videos can be watched:

- Old planes flying
- Aeroplane take-off and landing
- Minuscule - A good education
- Flying birds in the sky

Possible discussion questions:

- What kind of object is it possible to fly?
- What was the first man-made flying object?
- Is there any physical impossibility in Minuscule video?



Mechanics' Magazine,

MUSEUM, REGISTER, JOURNAL, AND GAZETTE.

No. 1520.] SATURDAY, SEPTEMBER 25, 1852. [Price 3d., Stamped 4d.

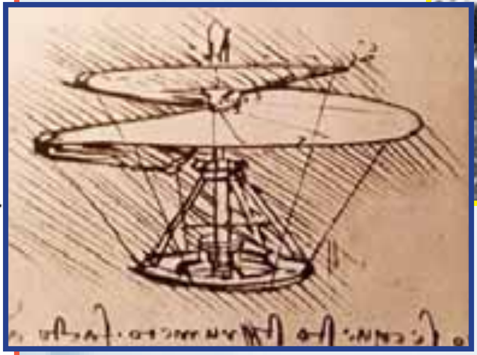
Edited by J. C. Robertson, 166, Fleet street.

SIR GEORGE CAYLEY'S GOVERNABLE PARACHUTES.

Fig. 2.

Fig. 1.

VOL. LVII.



Define questions from current knowledge

In this phase teacher asks pupils to define what forces do affect in the following situations. The questions are pondered from the standpoint of Newtonian mechanics.

1) What forces do affect an airplane when it is waiting its turn on the airstrip?
The airplane interacts with Earth:

- Earth attracts the airplane
- The airplane attracts Earth with a gravitation force that is equivalent, but opposite (Newton III)

2) What forces do affect a hang glider when it is to going to jump from a precipice down?
The hang glider interacts with Earth:

- Earth attracts the hang glider
- The hang glider attracts Earth with a gravitation force that is equivalent, but opposite (Newton III)

3) What forces do affect a flying object?

- This is the question which is searched for an answer during the following investigations.

Plan and conduct simple investigation

Pupils construct model planes in small groups. In the beginning of small group work everyone draws his/her own idea of the best model plane. After that teacher can also show the following video of constructing a model plane:

How to make a model airplane?

When the model planes are ready, groups present their works to the rest of the class. Following questions can be given for pupils to be pondered in presentations:

- What is the best design of the model airplane?
- How do you balance the airplane?
- What is the meaning of the rudder?
- What is the meaning of bending the wing tips?

Gather evidence from observation

The teacher presents the Mini Wing Miniature exhibit and tells pupils what kinds of investigations will be done. The guidelines are provided with the Tool-Box. The investigations can be for instance in small groups.

See the video of the use of Mini Wing Miniature exhibit.

With the Mini Wing Miniature exhibit are investigated the following situations:

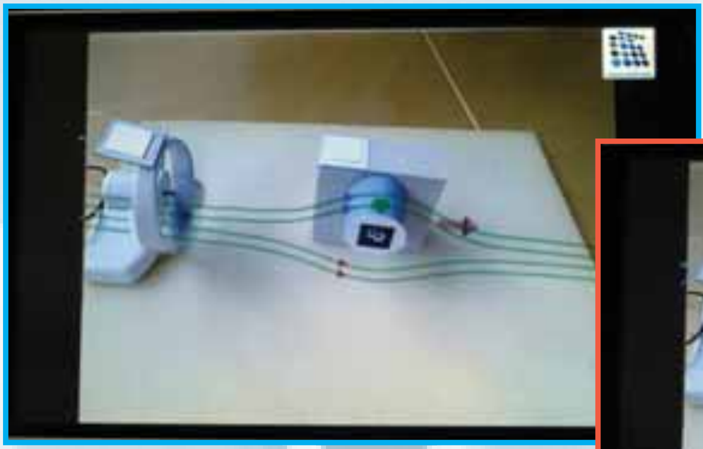
- take off • flight • landing

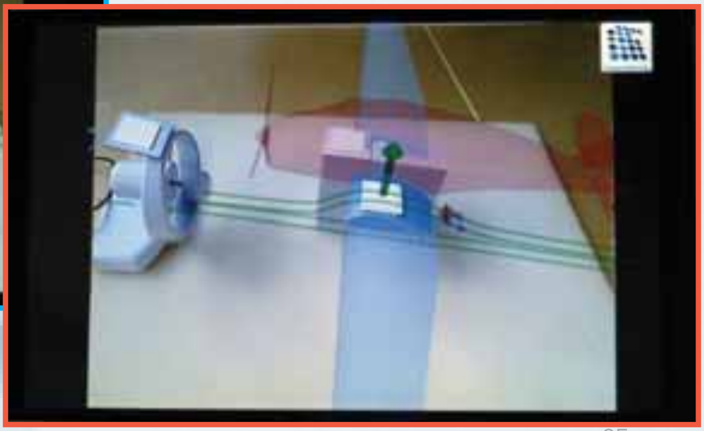
Also the different shapes of the wings are investigated:

- normal wing • wing with round cross-sectional surface
- wing with flat cross-sectional surface

Pupils do observe and discuss the affecting forces in different situations.

- How do these situations differ from the rest?
- What forces do affect the wing during takeoff, flight and landing?
- What are the directions of the forces?
- What is the strengthness of the forces?
- What forces do affect the hang glider during the gliding?





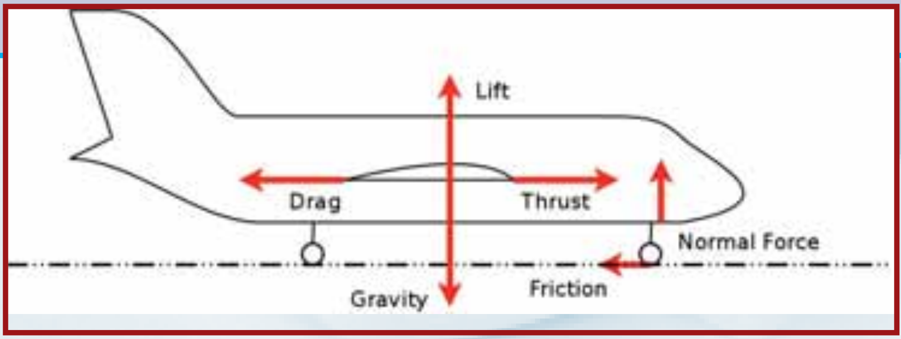
Explanation based on evidence

Teacher discusses with pupils about forces affecting the airplane and draws then a free body diagram of the airplane in flight. See an example of a free body diagram from supporting materials (airplane on the airstrip).

Wing dynamics
The airplane can take off and fly, because the wing of the plane turns airflow downwards, which generates lifting force as a counterforce (Newton III).

Forces affecting the airplane
- Vertical forces: Gravitation downwards Lift upwards
- Horizontal forces: Drag backwards and Thrust forwards

When does the airplane takeoff?
The plane takes off when lifting force (Lift) is equal to gravitation (limit speed).



Airplane, Simple Scientist

Consider other explanations

Teacher asks pupils to think in small groups free body diagrams of the airplane in all investigated situations: take off, flight and landing. Then these free body diagrams are drawn together for instance on the blackboard.

Takeoff
Strong Lift upwards,
Strong Drag (air resistance) backwards

Flight
Equilibrium:
Gravity = Lift
Drag = Thrust

Landing
Lift < Gravity landing
Drag backwards

Communicate explanation

Pupils do present a report based on their findings during investigations with Mini Wing Miniature Exhibit and the whole pathway.

Follow-up activities and materials

The flight of the airplane can also be thought from the standpoint of Bernoulli's principle.

- Bernoulli's principle
- The aerodynamics of flight

Scenario D
Mini-cooler & heater
(kinetic theory of gases)

Description:

The students make a short study of heath and molecular velocities using Science Centre To Go Mini Heater et Cooler exhibit. The demonstration of the experiment is based on advanced visualization techniques.

Guidance for Preparation Theory

(Find here some useful theoretical aspects of the experiment)

The early gas laws were developed at the end of the 18th century, when scientists began to realize that relationships between the pressure, volume and temperature of a sample of gas could be obtained which would hold for all gases. Gases behave in a similar way over a wide variety of conditions because to a good approximation they all have molecules which are widely spaced, and nowadays the equation of state for an ideal gas is derived from kinetic theory. The earlier gas laws are now considered as special cases of the ideal gas equation, with one or more of the variables held.

Experimental Set-Up

The demonstration/experimentation includes two main set-ups.
The first experimental setup includes:

- A cylinder with piston. Medical injection syringe is good.
- Hot and cold water, ice cubes are good to make the water cold.
- Science Center to Go AR Software
- Science Centre to Go Mini Cooler & Heater Exhibit
- PC and projector
- Access to the Internet

Learning Time: more than two hours

Age Range: 15-18

Exhibit curiosity

Teacher makes with students a little investigation into the gas laws.

The equipment needed are

- A cylinder with piston. Medical injection syringe is good.
- Hot and cold water, ice cubes are good to make the water cold.

The investigation is qualitative by nature. The purpose of it is just demonstrate, that air and other gases tend to expand when heating and contract when cooling.

The question that should rise from observations is: What happens in the molecule level in the gas. Why hot gas expands and cold contracts?

Define questions from current knowledge

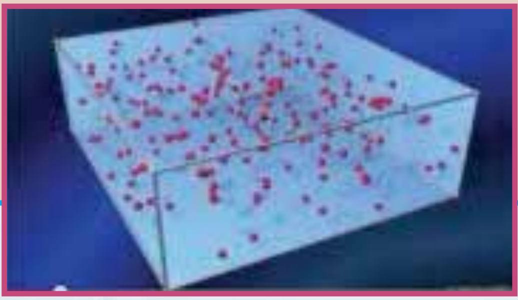
The observation is: The volume increases, when the temperature rises and vice versa the volume degreases, the temperature falls. What does this mean in a molecule level?

- The molecules of the gas have similar thermal expanding as solid objects. The size of the molecules changes when the temperature changes?

- The molecules need more space, when the gas is heated.

- The essential question is: "Is it possible to solve the mechanism of gases thermal expansion in molecular level using macro level observations?"

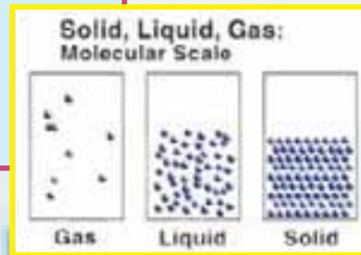
- Students will discuss about this in small groups and every group will give one answer, with justifications.



Propose preliminary explanations or hypotheses

Students will think why the explanation of the thermal expansion of the gases is better using the movement of gas molecules than using the thermal expansion of the gas molecules themselves.

- Gas is so thin prepared to the solids and liquids, that the size of the gas molecules must be irrelevant.



Plan and conduct simple investigation

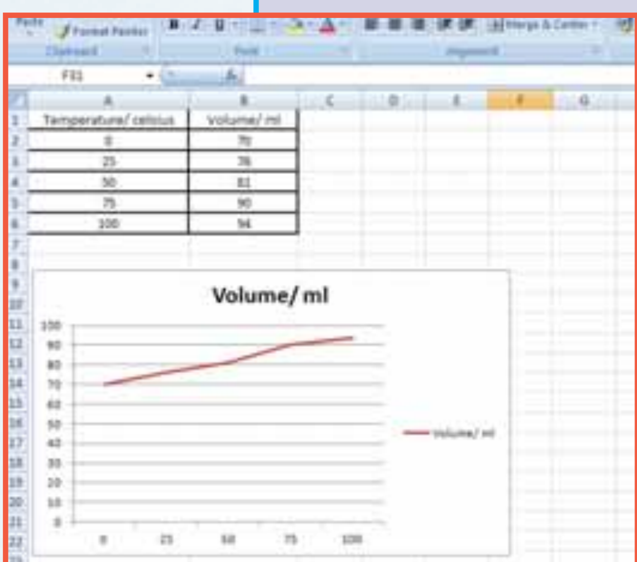
Students will make not only qualitative but also quantitative investigation into the relationship between the temperature and volume of a gas. The equipments are still the same + thermometer. Students measure the temperature of water using 4-5 different temperature in a range 0 - 100 degrees Celsius and the volume of the air in the syringe. Then they will draw a plot from the data. The results using this kind of simple equipment are rather rough, but it is easy to imagine, that the relationship is linear and the plot is a straight line.

Next step is to find the mathematical relationship between temperature and volume. This is basic mathematics in the second grade. The equation of the straight line in this case is y = 0,25*x - 270.

Very obvious question is: “What is the temperature, if volume is 0 ml?”

Answer is that temperature is -270 Celsius degrees. It has to be the lowest temperature, because the volume cannot be negative.

Finding the absolute zero point is better with a proper plot blogger program. Excel is not good for this purpose.



Gather evidence from observation

The teacher is using the Mini Cooler & Heater exhibit, following the guidelines that are provided with the Tool-Box.

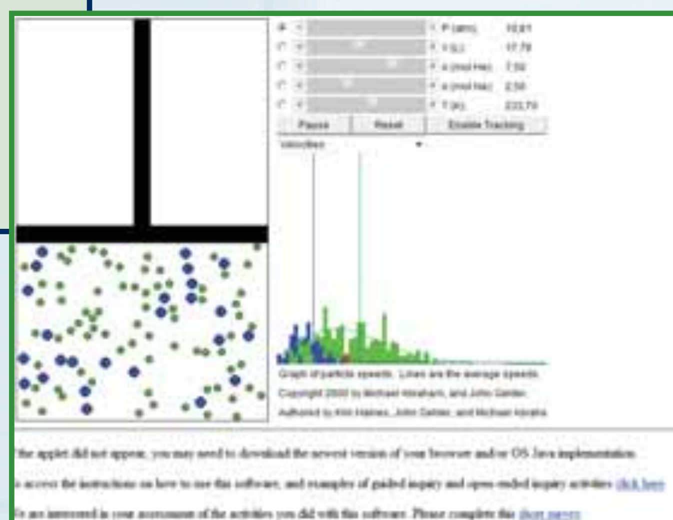
The teacher shows, how the system works. Then the students start to study. The main purpose is to solve, what kind relationship is between the the gas molecules and temperature of the gas.

There are some questions, which the Mini Cooler & Heater exhibit gives answers to, but many questions might remain unanswered. Like

- What kind mathematical model is between temperature and gas molecules?
- Are the velocities of the gas molecules uniform or do they have some kind distribution?
- Do different gas molecules behave different? For instance oxygen and nitrogen molecules, the main elements of the air.
- Do atoms and molecules as a gas state behave different ways? For instance noble gases vs. biatomic gases or triatomic non symmetrical gases like water vapour.

Explanation based on evidence

Good way to explain the relationship between temperature and gas molecules is to use proper interactive teaching program. Some of them are more qualitative, some quantitative.



Consider other explanations

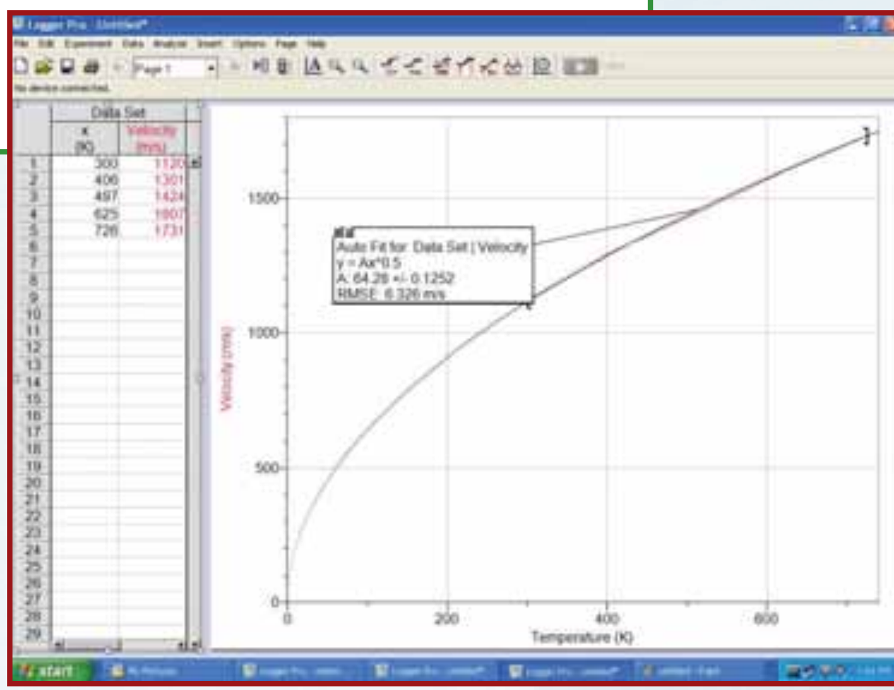
$$\frac{1}{2}mv_{rms}^{2}=\frac{3}{2}k_{B}T.$$

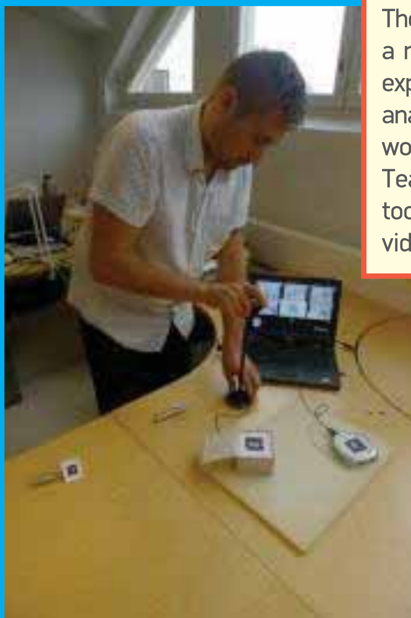
It is important, that the students understand, that temperature is a macro property of matter and the velocity of molecules is a micro property of the elements of the matter. In gases they are linked to together by an equation

The students use this program Molecular Speed Calculation to find how the velocity of gas molecules depends on temperature.

Students can use the ready Excel-sheet, which plots the v(T) graph. Note that temperature must be in Kelvin degrees.

Many data-collection and analysis application like Logger Pro 3 are also very handy for this purpose.





Communicate explanation

The students should report on the realized activities. The will need to prepare a report that includes the rational of the experiment, the initial design of the experimentation, the experimental set-up, the realization of the process, the analysis of the findings and a detailed discussion on the results. Students could work in groups, prepare their reports and then present them in the classroom.
Teacher should encourage the students to use photos and videos as research tools. The modern cell phones have many useful properties, not only photo and video camera.

Follow-up activities and materials

Good links and tests
Very nice interactive animation about gas laws
Interactive animation about states of matter
Another interactive animation about gas laws. The velocity distribution depending on temperature is very clearly to see.

Supporting materials:
- Gas properties activity
- Kinetic theory of gas atoms

Scenario E
Mini-double slit (quantum mechanics)

Description:

Students will perform the double-slit experiment in order to learn about the concept of wave - particle duality, the cornerstone principle of quantum mechanics. The demonstration of the experiment is based on advanced visualization techniques.

Educational Objectives:

to understand: Students have the opportunity to learn about the wave-particle duality and understand the nature of elementary particles by carrying out the famous double slit experiment.

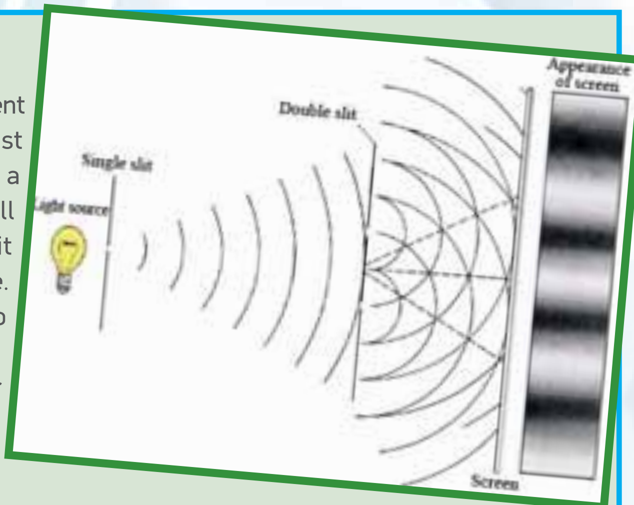
conceptual knowledge: Students learn about the nature of light and electrons and understand how different phenomena that we observe are produced.

to recognize values: Students get to explain phenomena that occur in everyday life by learning about the nature of light.

Learning Time: more than two hours

Age Range: 16-18

Guidance for Preparation



The double-slit experiment is a classic physics experiment first performed in the early 1800s by the English scientist **Thomas Young** in an attempt to resolve whether light is a particle or a wave. Using sunlight diffracted through a small slit, Young projected the light rays emanating from the slit onto another screen containing two slits placed side by side. Light passing through the pair of slits was then allowed to fall onto another screen.

Young observed that when the slits were large, spaced far apart and close to the next screen, then two separate patches of light formed on the screen. However, **when he reduced the size of the slits and brought them closer** together, **the light** passing through the slits and onto the screen **produced distinct bands of color separated by dark regions in a serial order**, known as interference patterns. These patterns could only be produced if light were acting like a wave. Then in 1905, Albert Einstein showed that light is a collection of discrete particles, which that he called "photons." When the double-slit experiment is repeated using single photons, an interference pattern is also seen, despite the notion that a single particle shot toward the screen should not be able to interfere with itself. The fact that light sometimes behaves as a wave and sometimes behaves as a particle is known as the wave-particle duality. **Subatomic particles like electrons exhibit a similar wave-particle duality**. The attempt to discover why this occurs has generated numerous theories, from Niels Bohr's Copenhagen interpretation to Hugh Everett's Many-Worlds interpretation.

Experimental Set-Up

The demonstration/experimentation includes two main experimental set-ups. The first includes the experimental set-up for the demonstration of the light interference. This could be easily demonstrated with the use of a laser pointer. The second experimental set-up is based on the use of the Double Slit miniature exhibit that has been developed in the framework of the Science Center to Go project. You will need:

- Laser Pointer and a Vernier
- Science Center to Go AR Software
- Science Centre to Go Double Slit Miniature Exhibit
- PC and projector & Internet access

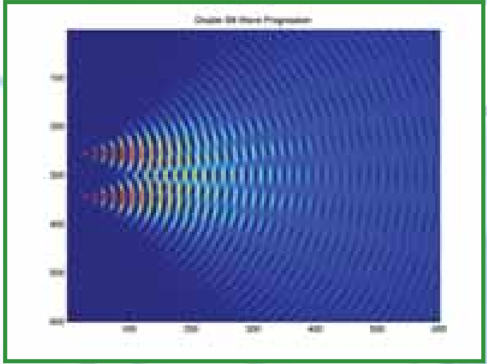
Question Eliciting Activities

Exhibit Curiocity

A great presentation by Michio Kaku (Parallel Worlds) on the **Nature of Light (time slot 1.30-5.20) can be presented to the students as an introduction to the double nature of light.**

You can repeat the Michio Kaku demonstration by using the laser pointer (fixed in a specific place) and the vernier to create the small slit that the light goes through. Following the Michio Kaku you can demonstrate to your students the "disappearance" of light after the slit.

You can also present them the case of sea waves interference which is described in the video. Here is a photo of the sea wave interference from the **"Voidokilia Beach"** at the SW end of Peloponnesus, Greece (This is claimed to be the port of Pylos, the kingdom of wise **King Nestor**).



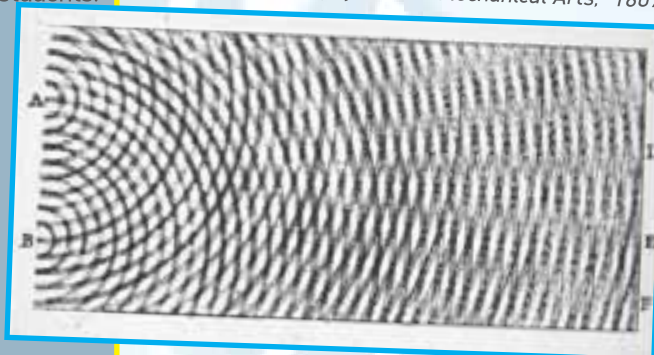
Voidokilia beach - Pylos, Greece

Define questions from current knowledge

Following the demonstration (dissapearance of light) you can introduce a series of questions to your students:

- **What kind of waves do you know of?** The main focus should be on electromagnetic waves and their properties.
- **What happens when waves interfere?** The ideas of constructive and destructive interference are discussed along with the interference pattern produced.
- **Why do we refer to light as electromagnetic waves and as photons at the same time?** Is it a wave and a particle at the same time?
- **What is light?**

From T. Young, "Course of Lectures on Natural Philosophy and the Mechanical Arts," 1807.

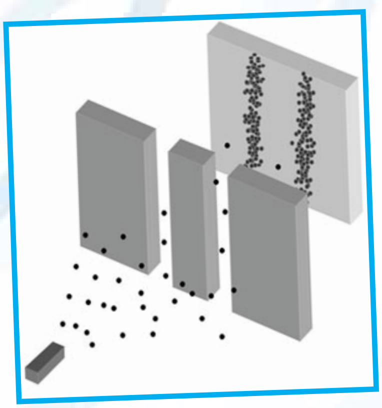


At this point we can introduce to the students the following experiments (we can show to them the experimental device):

a) In one experiment **light** is travelling from a source to a photographic plate, through a double slit.

b) In a second experiment **electrons** are travelling from a source to a detecting screen, through a double slit.

c) In a third experiment **marbles** are travelling from the source to an array of collecting bins, through two slit-like openings, side by side.



The figure on the left shows the experimental set-up. You can ask the student to make graphs show roughly the possible patterns which could be detected on the various screens.

Active Investigation

Propose preliminary explanations or hypotheses

The teacher asks the students to present their ideas and to make some initial hypothesis about the nature of the electrons: should they behave like light or like the marbles?

(This part of the exercise is of great importance as it is the cornerstone of the inquiry process and extra attention should be paid. It is vital to have students make predictions and after performing the experiment come back to them and revaluate their initial prediction so as to realize where and why they were wrong).

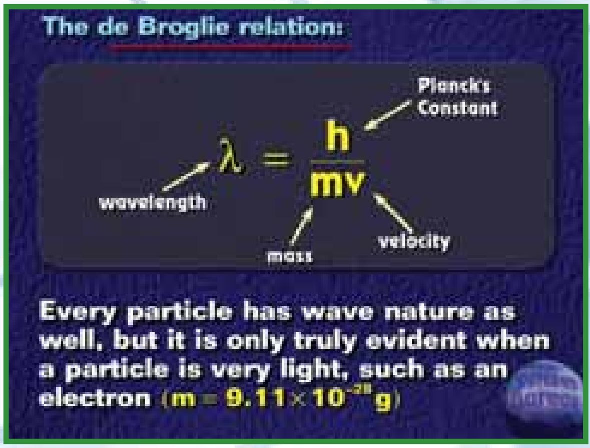
Common Students' Misconceptions:

The most common misconceptions are:

1. Electrons must be a particle (they must behave like the marbles), not a wave.

2. Electrons cannot dissapear. The position of a particle can always be known at a specific time.

After students have made their predictions the teacher presents the de Broglie hypothesis. Luis de Broglie received the Nobel Prize in Physics for his Hypothesis. Students can also be given a link to his Award Ceremony Speech (December 10, 1929).

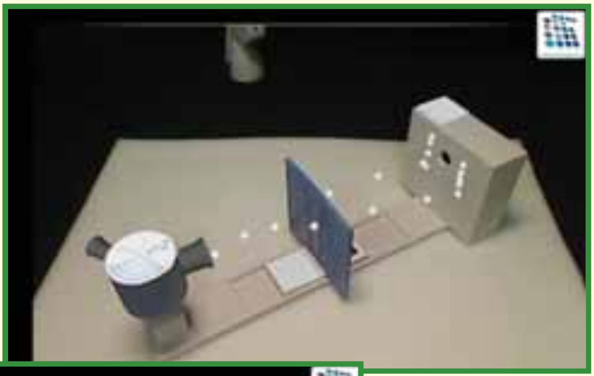


Plan and conduct simple investigation

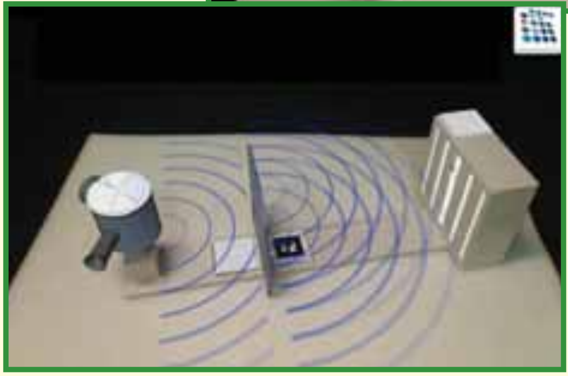
Augemented Reality is presented to the students. It is noted to them that this technology is used to visualize (through augmentations) the invisible. For example we are not able to see the electrons as we have done in the experiment with the laser.

The system allows to demonstrate all the phases of the proposed experiment. The teacher should prepare so he can start at a later stage to present to the students

(a) the classical particle case



(b) the wave case



(c) the quantum case

where interference pattern is presented to the screen behind the frame with the slits.

Observation / Experiment

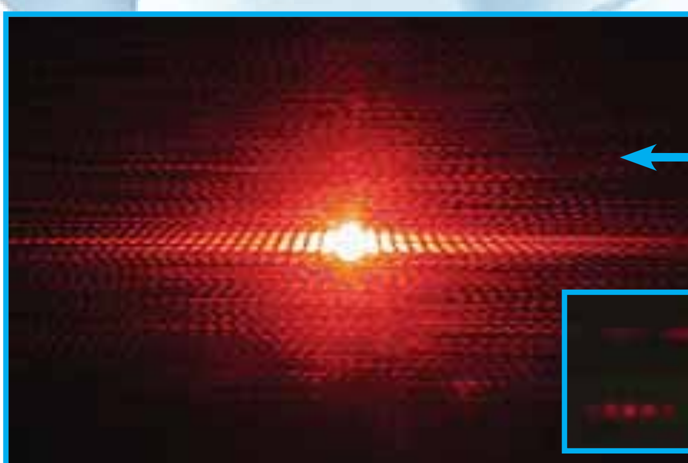
Gather evidence from observation

The teacher is using the Double Slit Miniature exhibit, following the guidelines that are provided with the Tool-Box.

a) First the system is set at the “wave” mode and the **interference of simulated waves (light)** is observed.
b) Then the system is set at the “particle” mode and the **case of marbles (classical particle)** is studied.
c) Then the case of **electrons (quantum particle)** is studied.

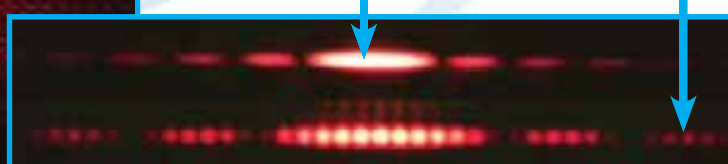
At each stage of the experiment students write down their observations and outcomes **(a detailed worksheet is provided).**

The Interference of light is shown through a simple experiment with a laser pointer and single / double slits.



Laser beam through a single slit (use Vernier

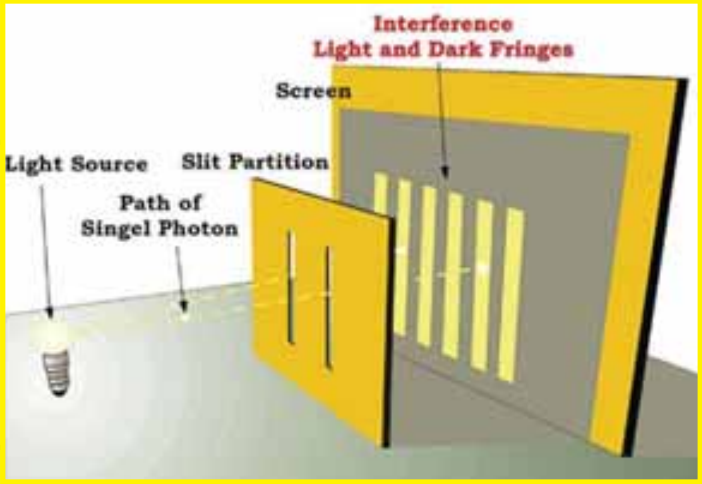
Laser beam through a double slit

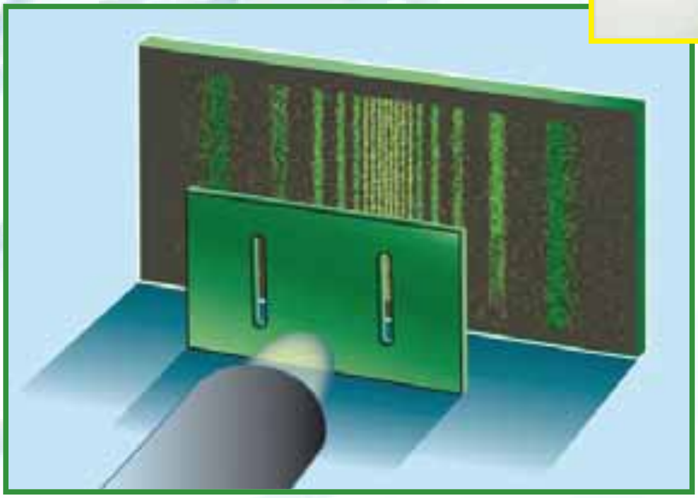


Explanation based on evidence

Based on the observations teacher explains that electrons present a wave-like behavior when they are going through the double-slit frame. **Their behavior is exactly the same with the behavior of the waves that interfere and the behavior of the photons.**

Dr. Quantum is a series of videos available online that provide a **simplified explanation** of the Double Slit Experiment. At this point it is recommended to present to the students this game-like animation that summarizes the whole process. It is very important to keep their interest high as in the following activities quite complex phenomena are going to be discussed and analyzed.





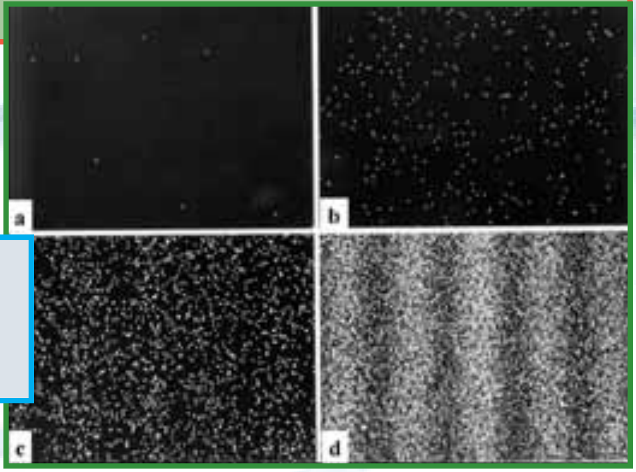
Discussion

Consider Other Explanations

To get an interference pattern we take a wave, split it up into two parts, send each part through one of the slits, and then recombine the waves. **Does this mean that a single electron is somehow going through both slits at once?** Another explanation that could be possibly given about **the origins of the interference pattern is that the electrons going through the left slit are somehow interacting with the electrons going through the right slit.** Note that we have no idea what such a mechanism could be, but are a little desperate to understand what is going on here.

We can explore this idea by slowing down the rate of electrons from the gun so that only one electron at a time is in the system. What we do is fire an electron, see where the flash of light occurs on the phosphor screen, wait a while for everything to settle down, then fire another electron, noting where it lands on the screen. After we have fired a large number of electrons, we will discover that the distribution of electrons is still the interference pattern.

The conclusion of all this is that there is no experiment that can tell us what the electrons are doing at the slits that does not also destroy the interference pattern. This seems to imply that there is no answer to the question of what is going on at the slits when we see the interference pattern. The path of the electron from the electron gun to the screen is not knowable when we see the interference pattern. As Heisenberg said, "The path [of the electron] comes into existence only when we observe it."



The **Electron Interference Experiment** performed by Akira Tonomura and co-workers at Hitachi in 1989 demonstrates experimentally that in fact electrons should interfere with themselves.

Reflection

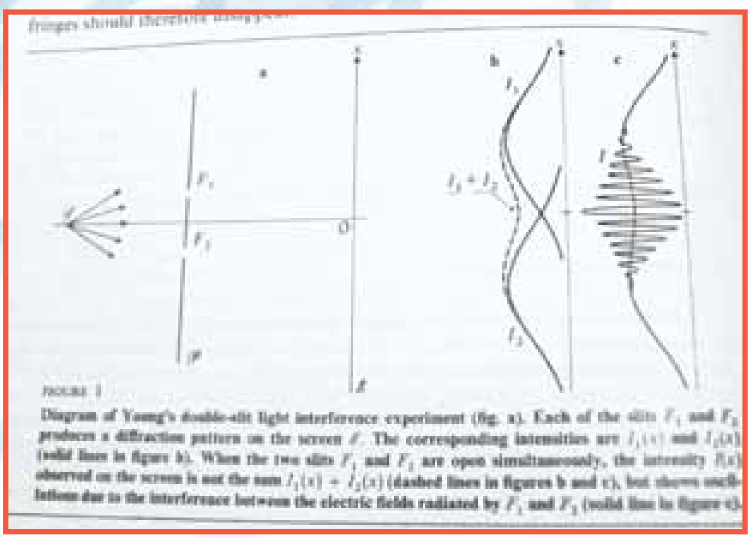
Communicate Explanation

The students should report on the realized activities. The will need to prepare a report that includes the rational of the experiment, the initial design of the experimentation, the experimental set-up, the realization of the process, the analysis of the findings and a detailed discussion on the results. Students could work in groups, prepare their reports and then present them in the classroom.

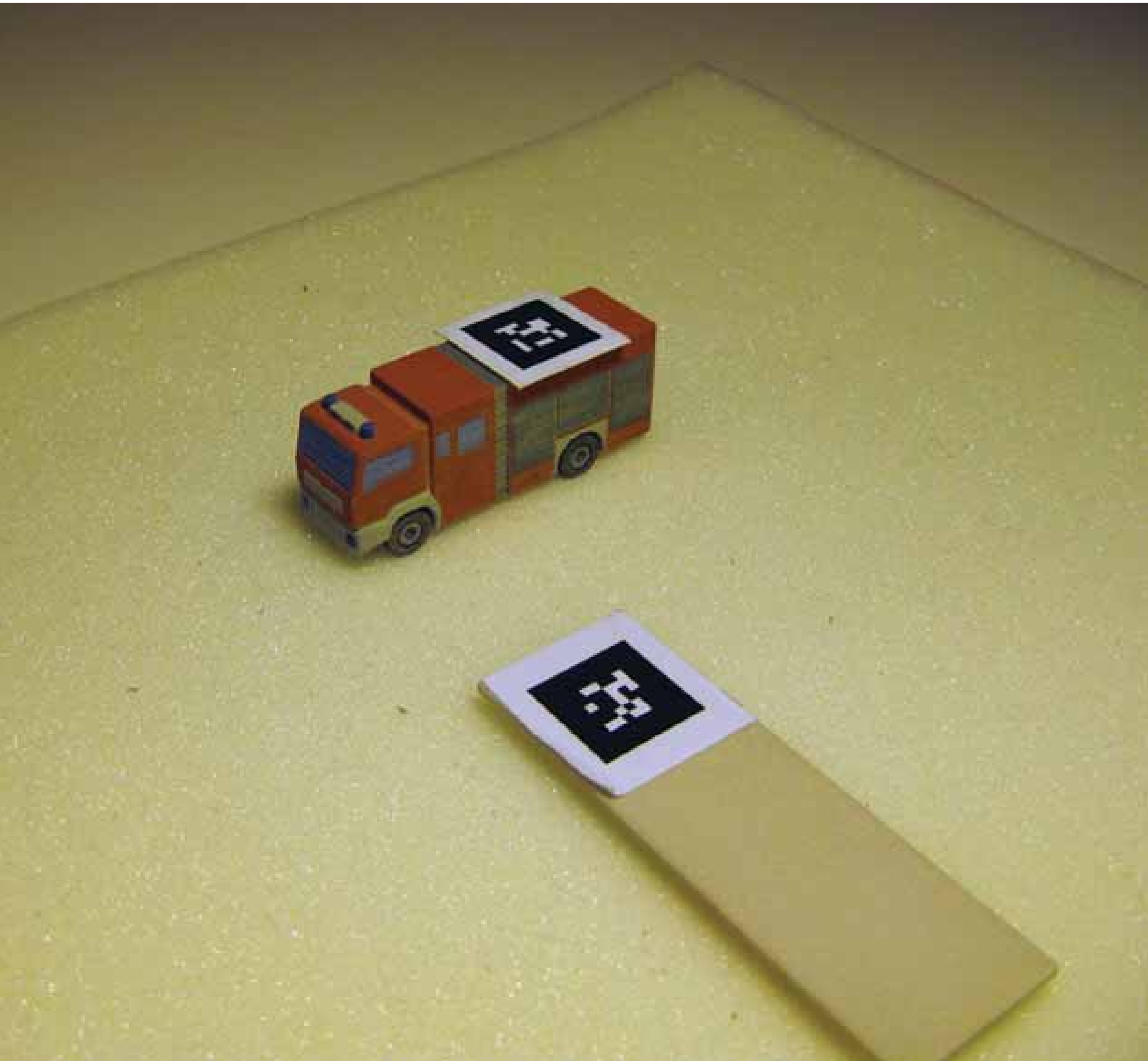
Follow-up Activities

For the assessment of the proposed activities a conceptual understanding test and a semi-structured interview template are proposed to be used as data collection tools (see 6.7 Appendix B and C). This interview includes two main questions that will teacher to investigate the consistency of students' perspectives across contexts by comparing students responses to the essay question on the double slit experiment (A) with a statement regarding the position of an electron in an atom (B). The interview has to take place following the realization of the experiment. It is important to make notes and to try and get detailed explanations of the students selections.

http://www.osrportal.eu/en/node/94689



5. Validation



5.1 Introduction

5.1.1 Objectives of the project

In contrast to Virtual Environments that completely immerse users into a virtual world, Augmented Reality (AR) combines the real world with artificial, computer generated elements. The mixture of real and virtual information, as a new kind of user experience conducted in a science centre, has been shown to positively influence students' intrinsic motivation, as well as cognitive learning, especially of low achieving students. It thereby can help to maintain pedagogical effectiveness [1, 2, 3]. However, the implementation of AR in school environments as a new way of learning was so far only realized and evaluated in very few cases [4, 5]. The basic objectives of this chapter are to adapt a tried and tested AR methodology of the consecutive projects CONNECT [6,7] and EXPLOAR [8, 9] to the needs of user groups in school classrooms as well as informal environments.

Consequently, the scope of this chapter is to present the validation of the SCeTGo approach in various formal and informal settings (school, university, science center) with different target groups (school students, university students, teachers, educators and researcher).

The validation of the SCeTGo project aimed at getting feedback of the users concerning the educational usefulness and its impact on science education. For that purpose the following questions were addressed as part of the validation process:

Does the SCeTGo approach...

1. ... raise interest in science and motivates you?
2. ... reach to induce engagement of students in experimental science learning?
3. ... lead to satisfying learning outcome, especially considering problem-solving and critical thinking skills?
4. ... offer teachers an enrichment of their everyday teaching practice?

We conducted a series of validation events in different European countries of participating institutions (Greece, Sweden, Finland, Spain, and Romania) in order to ensure that the objectives are achieved and the pedagogical effectiveness of SCeTGo project is given.

5.1.2 Participants

The adapted validation methodology (see section 5.2) was applied to the SCeTGo system firstly at schools as well as at universities and later on at informal learning settings (HEUREKA). An extensive validation was performed; participating institutions from Greece, Sweden, Finland, Spain, and Romania organized a series of national validation events in the framework of workshops conducted with teachers, pupils, university students, museum educators (HEUREKA) and experts from other areas of education (e.g. researchers from university).

5.2 Methodology - Validation Design

5.2.1 Empirical Evaluation Instruments & Data Analysis

Validation events were offered to two different user groups: Students from school and university as final consumer groups of the SCeTGo approach and teachers, science museum staff and researchers of the participating organizations as a "provider" group. Both groups have their own requirement and operate with the SCeTGo system in a different way.

We have to consider teachers needs, if we intend to make AR computer-mediated learning technology attractive to teachers: Teachers still act as key players in the use and acceptance of any new educational technology and there remains an enormous gap between developing AR technologies and its implementation in school [8]. Consequently, we adapted the validation instruments to the demands of the "provider" and the "user" group. Thereby this validation report is one of the few attempts to investigate the role of teachers' and students` acceptance of AR in school environments.

A knowledge test in a pretest-posttest design to get insight into students' cognitive achievements could not be conducted. A statistical power analysis revealed that requirements (sample size: number of participants) were not given to guarantee a valid statistical analysis. As part of the economic validation (VALNet; Economic Aspects) we asked for the integration costs of the ICT-based SCeTGo approach into the school system and the integration costs in general. Results for the integration costs in general are not shown, as we did not find a significant difference between the two questions.

5.2.2 Quantitative Methods – Questionnaires

The quantitative validation is based on pen-and-paper questionnaires. We applied a battery of items predicated on valid subscales, focusing on motivation, engagement and pedagogical aspects. Furthermore with regard to teachers` validations we assessed technological and economic aspects. Table 5.1 gives an overview of the instruments applied.

Questionnaire	Subscales applied (Number of items)	Adapted from:	Ref. to research question(s) No.:
	Students		
VALNet	Pedagogical Aspects (8)	MENON Network 2001	1,4
IMI (Intrinsic Motivation Inventory)	Perceived competence (6)	Deci & Ryan 1985, University of Rochester 2010	1,2
SMQ (Science	Personal Relevance (10)	Glynn et al.	1,2
Motivation Questionnaire)	Self-determination (4)	2009, Glynn & Koballa 2010	
Student engagement	Behavioral engagement (5) Emotional engagement (5)	Skinner et al. 2008	1,2
Knowledge test	[ad-hoc test] (20)	[ad-hoc test]	3
	Teachers		
VALNet	Pedagogical Aspects (5) Technological Aspects (3) Economic Aspects (6)	MENON Network 2001	4
IMI (Intrinsic Motivation Inventory)	Interest/Enjoyment (7) Value/Usefulness (7)	Deci & Ryan 1985, University of Rochester 2010	4

Table 5.1: *Overview of the instruments for the validation procedure.*

5.2.3 Qualitative Methods – Interviews

Additional to the quantitative tools, workshop leaders conducted interviews that followed a fixed interview grid. The content deals with the questions described in Table 5.2. We addressed questions with regard to teachers' and students` motivation to use the system in consideration of usability and pedagogical aspects.

Interviews were performed as follows: After the successful implementation of validation events, workshop leaders consulted participants willing to be interviewed. Interviews had an average duration of 20 minutes. To guarantee homogeneity of data, interviewers followed general principles according to descriptions of Lamnek [10]. All questions were adjusted in an open form and interviews were incorporated in a trustful situation. Interviews were analysed following Mayring`s qualitative content analysis [11]. A category was formed, if not less than two interviewees referred to the same aspect.

Questions	Teachers	Students
1. a) How did you take notice of the SCeTGo workshop?	x	-
1. b) Did you look forward to the SCeTGo lesson?	-	x
2. a) What have you expected from the SCeTGo workshop/lesson?	x	x
3. Did the SCeTGo workshop/lesson come up to your expectations?	x	x
4. a) Are you motivated to take use of the SCeTGo approach in your future lessons?	x	-
4. b) Did the lesson raise your interest in science?	-	x
5. a) What do you think are the most positive features of the SCeTGo approach	x	-
5. b) What do you think are the most positive aspects of this learning scenario, of this way of teaching?	-	x
6. Is there something you didn't understand, concerning the usage of the SCeTGo/computer-assissted exhibits?	x	x
7. Are you satisfied with the SCeTGo workshop/lesson?	x	x

Table 5.2: *Summarized overview of the interview grid questions.*

5.2.4 Validation events – Overview

In general a validation event was conducted as follows:

1. Presentation of the SCeTGo project.
2. Introduction to Inquiry-Based Science Education (IBSE).
3. Introduction to Augmented Reality (AR).
4. Presentation of the SCeTGo suitcase.
5. Demonstration of each miniature (participants could test all miniatures by themselves).
6. Filling out questionnaires.
7. In phase B miniatures were presented with the corresponding scenarios. Details of the unique events are given in chapter 4.

The projects` implementation comprised three phases:

1. Teachers training seminars: Introduction of the SCeTGo approach to partners of participating institutions. Partners were trained by consortium members in order to become workshop leaders and to get skilled with the SCeTGo system, the miniatures and all other relevant tools (webcam, markers etc.). The workshop included a demonstration of the 5 miniatures (Bolzmann experiment, Doppler experiment, Mini Wing experiment, Double Cone experiment, Double Slit experiment) and a practical part, where participants had the possibility to make own experiences.

2. Phase A (pilot phase): First cycle of implementation (01.07.2010 – 01.02.2011) conducted at schools/universities

Validation events were offered to pre-service teachers and teachers (1) and students from school (2). During events, participants got information about the project, the Augmented Reality (AR) technology and its application in classrooms. Teachers (1) were given an introduction about technological aspects, including an explanation about the handling of the tool. They got used to the SCeTGo suitcase and its handling, it 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. A detailed description of the suitcase and the application of the different miniatures is found in the SCeTGo user manuel. Additionally participant could interact with all exhibits and AR features that were developed in the framework of the SCeTGo system.

In contrast to teachers` validation, only one miniature was shown to each students` group (2) to get a detailed validation of each miniature.

3. Phase B: Second cycle of implementation (01.02.2011 – 01.12.2011) conducted at schools/universities/ science center

In the second phase, science museum staff and researchers (from universities and schools) (1) of the participating organizations were included as a "provider" group and students from university as a user group (2). In order to enhance quality of the interactive visualization technology of the miniature exhibits, miniatures were revised according the the validation outcomes conducted during phase A. Additionally animations of physical processes in the classroom were accomplished by pedagogical scenarios, that are tangential to the curriculum. An inquiry-based learning scenario was performed as follows:

Phase 1: Question Eliciting Activities
Phase 2: Active Investigation
Phase 3: Creation/ Formation
Phase 4: Discussion
Phase 5: Reflection

This way the SCeTGo setup assures an innovative inquiry-based learning approach that is tailored to students` needs and implements not only "hands-on", but also 'minds-on' experiments. Moreover, it allows teachers a successful application within school curricula without the need to a time consuming preparation of teaching material. In phase B revised miniatures with the corresponding learning scenarios were presented to both groups (1&2).

5.3 Execution of the validation events

Table 5.3 shows a summary of validation events conducted between 01/07/2010 – 01/02/2011 (phase A) and 01/02/2011 – 01/12/2011 (phase B). A detailed description of each event is provided in Table Table 5.4.

	Students` questionnaires	Students` interviews	Teachers` questionnaires	Teachers` interviews	Researchers` interviews	Museum staffs` Question-naires
Romania	513	35	27	17		
Finland	-	-	72	29		
Total Phase A	513	35	99	46	-	
Sweden	73	8	9	3	-	-
Spain	-	-	20	2	-	-
Greece	55	5	17	15	14	-
Romania	64	-	19		-	-
Finland	112	-	3	-	-	22
Total Phase B	304	13	68	5	14	22
Total:SCeTGo A&B	817	48	167	51	14	22

Table 5.3: *Summarized overview of the validation events conducted in implementation phase A and B.*

Phase	Partner	Place	Date	Participants
A	Romania	Cluj Napoca (CCD Cluj)	2- 3/11/2010	35 physics teachers
A	Romania	17 schools from the Cluj county	4-11/11/2010	513 students
A	Finland	Heureka	25-26/11/2010	124 students, from the University of Helsinki, department of teacher education 2nd – 3rd class
B	Greece	Project meeting in Athens	1- 3/12/2010	12 project team members
B	Spain	University of Barcelona (UB) – Faculty of Pedagogy	17/5/2011	20 pre-service science teachers (secondary level)
B	Sweden	NO-Biennalen Halmstad	12/04/2011	25 teachers
B	Sweden	Gröndalskolan (school), Värnamo, Sweden	04/2011	73 school students (9th grade)
B	Sweden	Arabyskolan (school) Växjö, Sweden	31/5/2011	
B	Greece	Pathway Summer school, Crete , Greece	5 - 8/7/2011	app. 35 teachers
B	Greece	EDEN Open Classroom conference in Athens (Pallina)	27-29/10/2011	app. 18 teachers
B	Greece	Greek higher Military academy	18/11/2011	app. 70 university students, 7th semester (3 courses)
B	Romania		11/2011	64 school students (3 classes)
B	Romania		11/2011	19 teachers
B	Finland	Heureka	11/2011	11 participants, museum staff
B	Finland	Heureka	24-25/11/2011	143 university students

Table 5.4: *Conducted validation events in phase A and B.*

5.4 Results

5.4.1 Phase A, Quantitative Research

Survey of Teachers (formal learning settings)

During the implementation phase A of the SCeTGo system (01/07/2010 – 01/02/2011), all miniatures were introduced to 72 Finish pre-service science teachers and 27 Romanian in- service science teachers at schools within a professional development framework. Data assessed by questionnaires as part of the quantitative analyses are presented.

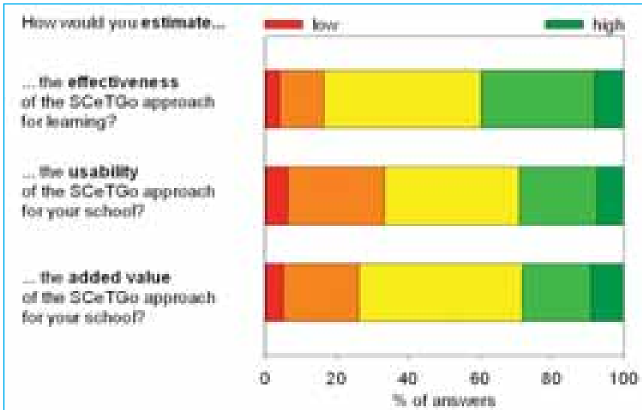


Fig. 5.1: Evaluation of Pedagogical Aspects I (VALNet)

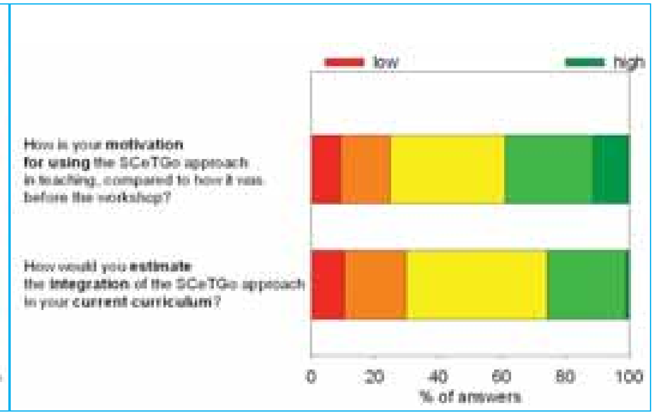
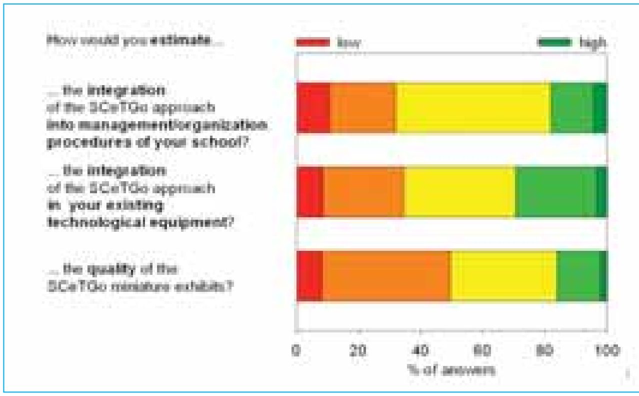


Fig. 5.2: Evaluation of Pedagogical Aspects II (VALNet)

To validate pedagogical, technological as well as economical aspects of the SCeTGo approach, we analysed teachers' answers to the VALNet questionnaire. Concerning pedagogical aspects, the majority of teachers (> 50%) think that the SCeTGo approach is effective for learning, usable for and adding value to their schools (Fig. 5.1).

Furthermore, the motivation to use the approach in teaching increased compared to before workshop participation. Teachers estimated the integration of the SCeTGo approach in the current as medium to high (Fig. 5.2). Thus, the pedagogical aspects of the approach were rated in a very satisfying way, indicating that teachers consider the approach to be pedagogical valuable.



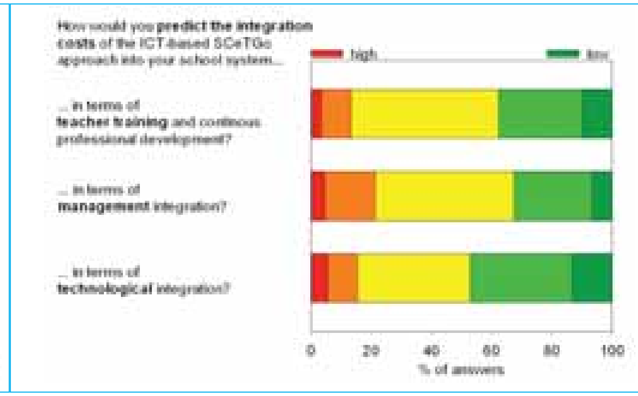


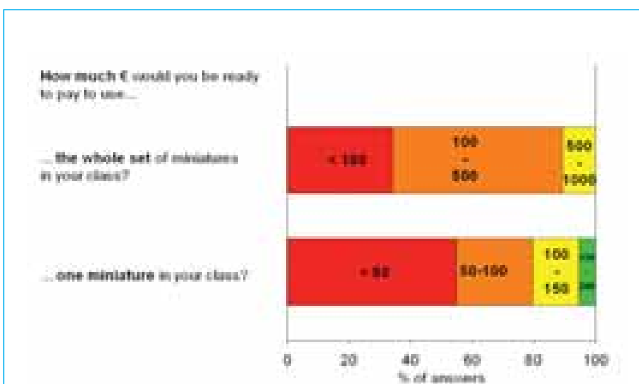
Fig. 5.3: *Evaluation of Technological Aspects (VALNet)*

Fig. 5.4: *Evaluation of Economical Aspects (VALNet) I*

Almost 70% of workshop participants rated the integration of the SCeTGo approach into organization procedures and in the existing technological equipment as medium high to high.

Slightly less teachers (50%) estimated the quality of the SCeTGo miniature exhibits as medium high to high (Fig. 5.3). This is a very positive result.

The majority of teachers predicted the integration costs of the ICT-based SCeTGo approach as medium (Fig. 5.4). Potential reasons might be that not only the SCeTGo suitcase, but also the ICT-equipment would have to be bought before using the SCeTGo approach in a proper way.



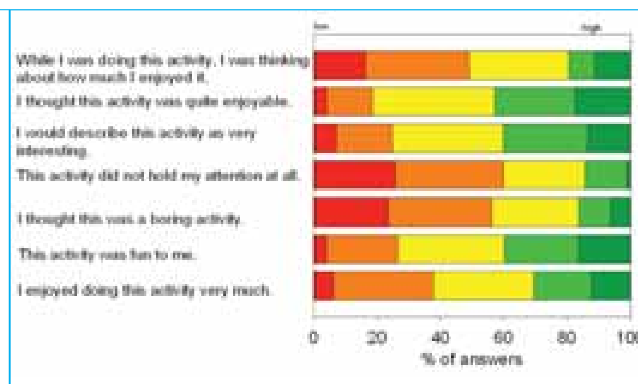


Fig. 5.5: *Evaluation of Economical Aspects II*

Fig. 5.6: *Evaluation of Interest/Enjoyment (Intrinsic Motivation Inventory)*

Interestingly the evaluation of economical aspects shows, that users are willing to pay more for one miniature in comparison to the amount of money they would pay for all miniatures (Fig. 5.5). This result proposes that they are more interested in the purchase of a single miniature than buying a whole set.

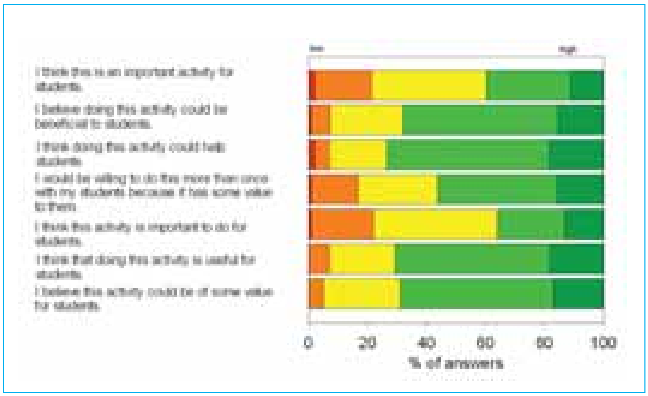


***Fig. 5.7:** Evaluation of Economical Aspects II*

To measure teachers intrinsic motivation, two subscales of the Intrinsic Motivation Inventory (IMI) were administered. On average, results show that teachers rated the value and usefulness of the SCeTGo approach better than interest and enjoyment. A possible reason for the relatively low interest and enjoyment may be that the approach mainly addresses younger target groups (students) and therefore, teachers might not have been challenged when working with the miniatures. However, value and usefulness were almost never rated low, so this is still a favourable result.

By validating the teacher workshops, we also wanted to find an answer to our 4th research question: Does the SCeTGo approach offer teachers an enrichment of their everyday teaching practice? Overall, the results of the validation of teacher workshops underlines the importance and quality of the SCeTGo approach for instruction. Therefore, the approach may indeed be a valuable enrichment for teaching practice.

Survey of Students (school)

Altogether, 512 students attended the validation events in phase A. Different to the teacher workshops, students worked with only one of the SCeTGo miniatures in each workshop to get a detailed validation of each miniature. Miniatures have been shown to adequate age groups between 14 and 18 years (Doppler Effect, grade 7-10; Miniwing grade 9, Double Cone 9, Boltzmann Constant grade 10; The Double – Slit Experiment grade 11). Each student filled out a questionnaire with regard to the miniature applied (Boltzmann experiment, 194 student questionnaires; Doppler experiment, 67 student questionnaires; Mini Wing experiment, 83 student questionnaires; Double Cone experiment, 55 student questionnaires; Double Slit experiment, 47 student questionnaires). Data analyses could show that results are similar for all miniatures, therefore we present the results for the Boltzmann miniature as an example because most students attended this workshop. Only the Double Slit miniature was rated slightly worse than the other miniatures. Therefore, the evaluation of perceired competence is shown additionally appendix.

Boltzmann Experiment

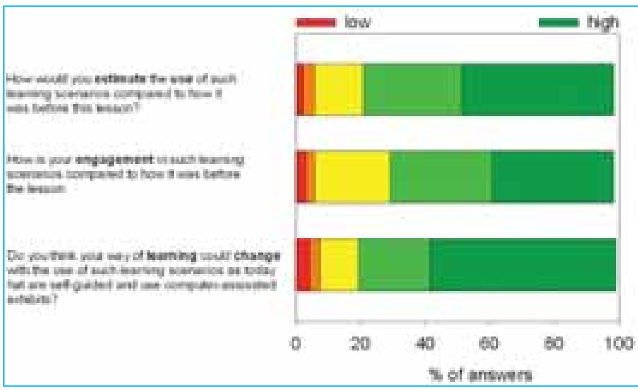


Fig. 5.8: Evaluation of Pedagogical Aspects I (VALNet)

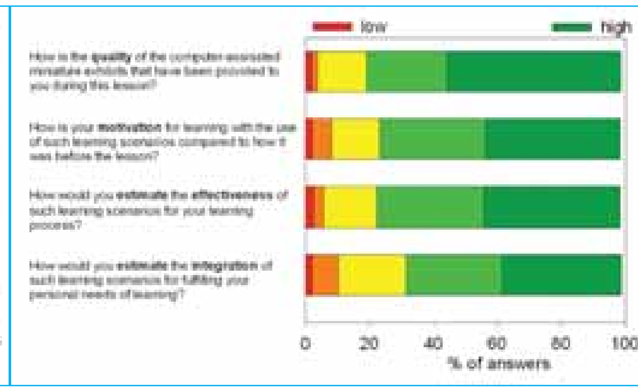
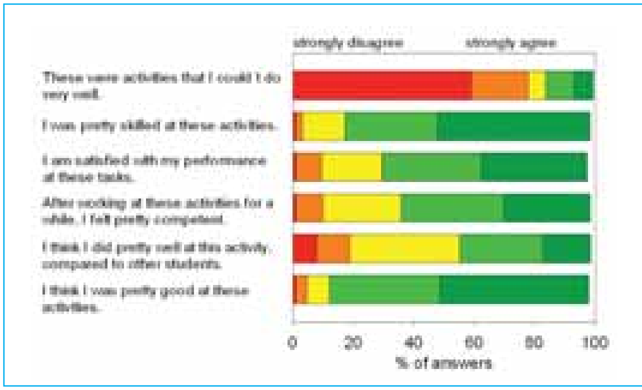


Fig. 5.9: Evaluation of Pedagogical Aspects II (VALNet)

Students were asked to assess the pedagogical aspects of the miniature they worked with. Results (Fig. 5.8 and Fig. 5.9) show that the majority of students consider the use of the learning scenario (app. 80%), its effectiveness for the learning process (app. 70%), and its integration for fulfilling personal needs of learning (app.70%) as medium high to high. About 80% of the students estimated the quality of the miniature they worked with as medium high to high. Similar ratings were given for the students' engagement in learning scenarios in contrast to before the workshop, the possibility of a change of their ways of learning and their motivation for learning by using such learning scenarios. In summary, the pedagogical aspects of the miniatures were assessed in a very satisfying way and underline the findings from the teachers' workshop validation: The SCeTGo approach may be a valuable enrichment for teaching practice. Referring to the first research question, the results show that students' interest in experimental science learning and science motivation could be raised or increased.



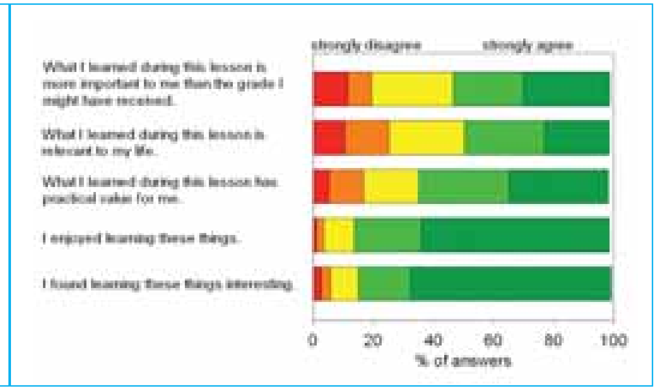
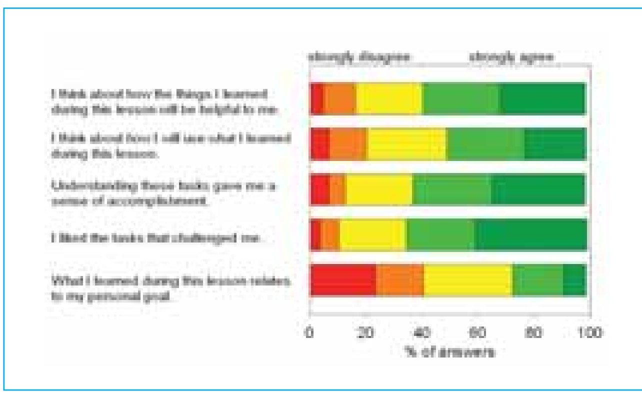


Fig. 5.10: *Evaluation of Perceived Competence (Intrinsic Motivation Inventory)*

Fig. 5.11: *Evaluation of Personal Relevance I (Science Motivation Questionnaire)*

With regard to perceived competence it stands out that students were self confident in reference to the task, only a minority (20%) thought that they could not do the activity very well.



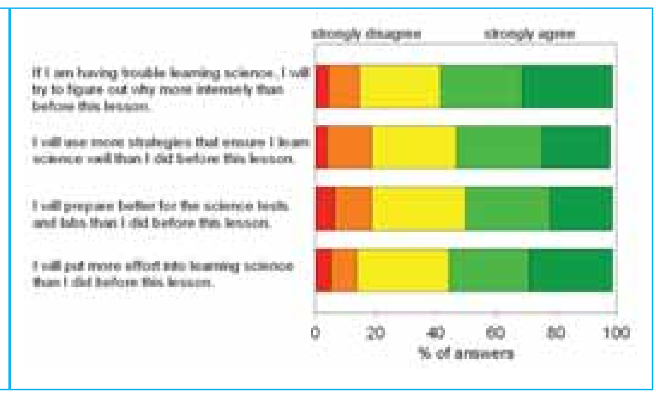
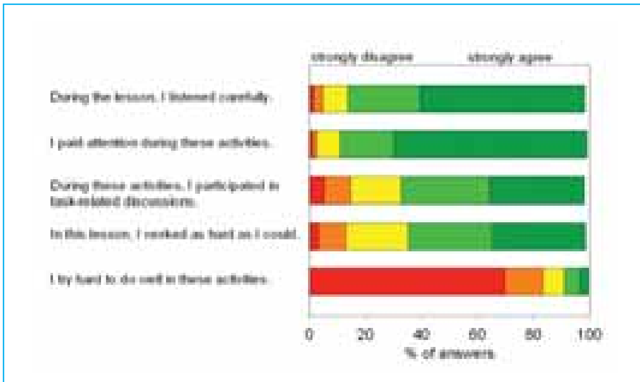


Fig. 5.12: *Evaluation of Personal Relevance II (Science Motivation Questionnaire)*

Fig. 5.13: *Evaluation of Self-determination (Science Motivation Questionnaire)*

We also administered the subscale "Personal relevance" of the Science Motivation Questionnaire (SMQ). Overall, the miniatures seem to have a high personal relevance to the students, although about 40% think that it does not relate to their personal goal. This seems contradictory as the majority stated that the lesson was relevant to their lives and has practical value to them.

In reference to their self-determination (Fig. 5.13) results were satisfying, more than 50% of students agreed with the questions asked.



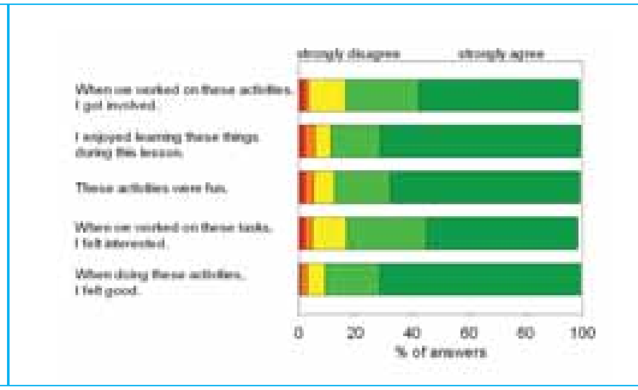


Fig. 5.14: *Evaluation of Behavioral Engagement (Student Engagement Questionnaire)*

Fig. 5.15: *Evaluation of Emotional Engagement (Student Engagement Questionnaire)*

Positive results can be found for students' behavioural and emotional engagement. Over 50% of the students showed a high behavioral engagement when working with the miniatures (Fig. 5.14). Especially the emotional engagement was rated very positive and indicates that students were very enganged while working with the miniatures (Fig. 5.15).

Overall, the results show that the SCeTGo approach raised interest in science and science motivation (research question 1), induced and increased engagement of students in experimental science learning (research question 2) and may also serve as an enrichment of everyday teaching practice (research question 4).

Double Slit Experiment

The Double Slit miniature was rated slightly worse (app. 10%) than the others miniatures. The evaluation of perceived competence may give an answer why it was evaluated not as good as the other miniatures. Fig. 5.1.2.16 is shown additionally to the Boltzmann experiment.

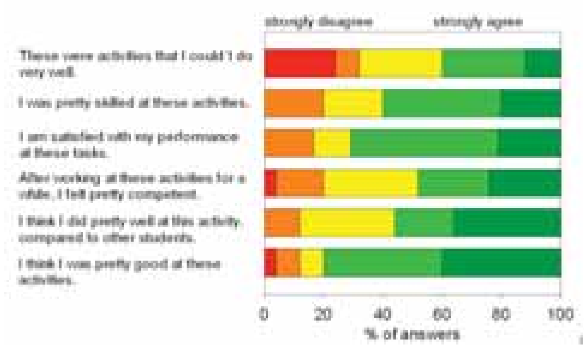


Fig. 5.16: *Evaluation of Perceived Competence (Intrinsic Motivation Inventory)*

Fig. 5.1.2.16 confirms that 40% of students agreed that they could not do the activity very well. The evaluation of perceived competence indicate that students were overburden with the activity, especially in comparison to the Bolzmann experiment, where only a minority (<20%) thought that they could not do the activity very well (Fig. 5.1.2.10). The Double Slit experiment was conducted with students of grade 11, the age group should be adequate. However, in phase A learning scenarios were missing, what could explain that students were overstrained.

5.4.2 Phase A: Qualitative Research

Survey of Teachers (formal learning settings)

The SCeTGo system miniatures were introduced to 72 Finish pre-service science teachers and 27 Romanian in-service science teachers at schools during the implementation phase A. Out of this group 29 Finnish pre-service science teachers (gender: female 22, male 7; average age: 26.8, range: 19-51 years) and 19 Romanian in- service ones (gender: female=16; male=3; average age: 45.8 range: 33-55 years) teaching physics, were asked about their attitudes towards SCeTGo and its carrying out in school.

We present a summarising content analysis (Table 5.5) integrating the results of individual interviews that have been conducted with the sample reported above.

A category was formed, if not less than two interviewee referred to the same aspect. Percentage to not refer to numbers of participants, but to the total number of answers given.

Participants were asked, if they were motivated to use the SCeTGo system in their future lessons. 75% agreed, 19% would not integrate the SCeTGo approach in instruction, 6% were undecided. Furthermore, in-service teachers and pre-service teachers, who indicated to use the exhibits, pointed out the most convincing features of SCeTGo: A visualisation of abstract phenomena was mentioned most frequently (38%), followed by an easy handling and a support during teaching (22%). In addition, they emphasized that they liked the hands-on activities (14%). However, only in a minority SCeTGo was estimated superior to books (4%).

All in-service and pre-service science teachers and practicing science teachers, who were not willing to take use of the SCeTGo exhibits were asked for their motives: In majority, interviewees referred to the prototype status of the miniatures (39%). Furthermore, they predicted miniatures to be to costly for an application in school (23%). Also some instructors found it to be difficult to understand all phenomena or would only apply some of the exhibits to practice (15%). In-service and pre-service science teachers highlighted several reasons, why they were motivated to take use of the SCeTGo exhibits: A majority of interviewees considered the less demanding theory in context of physical phenomena as a positive feature of SCeTGo (15%), followed by the illustrating visualization (13%). Interactivity (12%) and an innovative approach (10%) were positively emphasized. In addition inquiry based learning was stated as a positive aspect (10%). Further features referred to were a use of new technologies (9%), together with a great demonstration of physical phenomena (9%), a new teaching strategy (8%) and a user oriented design (7%). A connection to the curriculum, as well as a prevention of misconceptions was only mentioned in 4% of cases. Question 6 shows that the majority did not have problems, concerning the usage of the SCeTGo exhibits (65%). However, a minority felt uncomfortable to use the software (14%). The same ratio of interviewees found the physical phenomena difficult to understand and need more information (11%).

In summary questionnaires conducted in phase A could confirm that teachers evaluated the miniatures in combination with an AR technology as a valuable tool for instruction.

With regard to the specific objectives of the project (see 5.1.1) the qualitative analysis revealed that SCeTGo simplifies instruction, what implies that miniatures have a high value to teachers. Thereby, an AR enhanced learning system, as SCeTGo contributes to a new form of education.

Interview Questions	**Categories**	**Workshop Validation**	
		Number of answers	**%**
Gender	Male Female	10 38	21 79
a) Subjects I'm a physics teacher and I have a master degree in astrophysics.	Physics Chemistry Biology Subject not related to natural sciences	28 4 5 14	50 8 13 29
What level do you teach:	Primary Inferior secondary/ gymnasium Upper secondary/ highschool	10 20 18	21 42 38
0 b) Citizenship	Finland Romania	29 19	60 40
0 c) Age	20 – 25 25 – 30 30 – 35 35 – 40 40 – 45 45 – 50 50 -55	8 15 6 9 6 4 3	17 25 13 19 13 8 6
0 d) Applied miniatures	All miniatures applied (Doppler Effect, Double Cone, Mini-wing, Young's Double Slits, Molecule Movement)	48	100
1. How did you take notice of the SCeTGo workshop?	Part of an university course Teacher trainer informed me Personal interest No answer given	22 8 2 16	46 16 4 33

2. What have you expected from the SCeTGo workshop, concerning knowledge, attitudes, and values?	No anwer No expectations Interesting and basic knowledge Application to a new teaching form Understanding the usage	2 18 11 11 7	4 37 22 22 14
3. Did the SCeTGo workshop come up to your expectations, concerning knowledge, attitudes, and values?	Yes No In between	20 3 7	67 10 23
4. Are you motivated to take use of the SCeTGo approach in your future lessons?	No answer Yes No	3 36 9	6 75 19
If "yes": What exactly convinced you, to make use of the SCeTGo approach?	Hands-on approach Miniatures help with teaching Superior to books Easy handling Visualisation of abstract phenomena	7 11 2 11 19	14 22 4 22 38
If "no": Please mention the reasons, why you don't want to make use of the SCeTGo approach!	Tools need more development Would only use some of them Did not understand all phenomena Too expensive Too much effort	5 2 2 3 2	38 15 15 23 14
5. What do you think are the most positive aspects of the SCeTGo approach?	Innovative approach Easy to understand Great demonstration visualise invisible aspects of a phenomenon Use of new technologies in school New strategy Interactivity User oriented design Inquiry based learning Connection to the curriculum Prevention of misconceptions	9 14 8 12 8 7 11 6 9 4 4	10 15 9 13 9 8 12 7 10 4 4
6. Is there something you didn't understand, concerning the usage of the SCeTGo exhibits?	No Difficult to understand Feel uncomfortable to use the software Need more information	24 4 5 4	65 11 14 11
7. Are you satisfied with the SCeTGo workshop?	Yes No In-between	27 8 13	56 7 27

If "yes": What did you like?	Easy to use Application of a new technology Impressive tool/ technology Great idea Good teaching approach Great demonstration	12 17 15 9 11 8	17 24 21 13 15 11
If "no": What should be enhanced in future workshops?	Longer demonstration Software does not work to 100% Miniatures are so far only prototypes Instructors need more knowledge More explanations User manuals should be added Learning scenarios were missing User sheets for pupils should be added	4 9 6 8 8 5 3 4	9 19 13 17 17 11 6 9

8. Any comments?
Positive comments:

- It's cheaper than going to a science centre.
- Have to try it with pupils.
- Looking forward to see how it works in future.
- You can see things/phenomena you normally could not see.
- Great connection to real life.

Recommendations for improvements:

- Miniatures should work more accurately.
- There are still some bugs in the system.
- The Presentation is hard to organize in a classroom (everyone wants to see and wants to touch).
- Augmentations are not self-explanatory - more explantion is needed.
- Each exhibit should be accompanied by a user manual and educational activity.
- Teachers need proper training prior to usage concerning the technical and the scientific part.
- Great potential, but needs to be "revised".
- To be sold at schools it has to work 100 %.
- Some of the scenarios can not be implement as part of the existing curriculum.
- It is necessary to adapt the scenarios for the lower secondary level.
- New miniatures with regard to the leaning surface and the friction force should be developed.
- Miniatures are only at the beginning of a long way.
- A hand book with SCeTGo scenarios or a brochure would facilitate the usage of miniatures.

Table 5.5: *Summarizing content analysis of interviews conducted during the workshop with teachers in pilot phase A according to Mayring (2008). The categories to which the original answers to the interview questions were summarized are shown. Multiple nominations were possible.*

Survey of Students (school)

As part of students' validation of phase A miniatures were presented to 512 Romanian pupils, 6% of the participants were interviewed. Hereby, we show a summarising content analysis (Table 5.6), integrating the results of individual interviews that have been conducted with 32 Rumanian students (gender: 23, 9; age: 15.4, range: 12-17 years). A category was formed, if not less than two interviewee referred to the same aspect. Percentage to not refer to numbers of participants, but to the total number of answers given. All students asked if they were satisfied with the lesson answered in the affirmative. As shown in question 7.2 students were satisfied with the lesson, because they liked most contact with experts (26%). Furthermore they favored learning with real objects and real experiments (17%), same ratio of interviewees preferred a student-centered learning approach. In addition a lesson, different to everyday, school was looked upon as favorably as the innovative approach (11%). The multimedia aspect was mentioned in 10% of cases, to a lesser extend it was stated that learning with miniatures was fun (7%). Additionally, students were asked if the lesson raised their interest in science. Most of students answered positively (88%). Nobody negated the question and only a minority of students were unsure about this question (13%). The lesson raised students` interest in science for different reasons. In a majority something extraordinary, different from everyday class (30%) was stated as a cause. An interactive approach, as well a simplification of theory, easier in comparison to normal lessons was mentioned to a same amount (26%). In addition, a different way of learning provided by the exhibits was pointed out (18%).

Overall, the feedback given by pupils within the individual interviews was mostly positive.

According the data students really liked working and learning with the miniatures. They did not suggest any improvements. Students rated pedagogical effectiveness with regard to an increase in interest in natural science and enjoyment of the lesson positively.

In particular, the hands-on approach of the miniatures, the student-centered lessons and the multimedia aspects was accentuated. The application of the SCeTGo miniatures raised students` interest and activated the majority of participants to get more involved in science contents. The high percentage of interested students shows that most of them were inspired by the exhibits and the AR technology. With regard to the projects` objectives we could confirm that the SCeTGo approach raise interest in science and science motivation and reach to induce engagement of students in experimental science learning.

Interview Questions	Categories	Workshop Validation	
		Number of answers	%
Gender	Male Female	9 23	28 72
0 a) Grade/ Semester	6 7 8 9 10 11	3 0 5 8 6 10	9 0 16 25 19 31
0 b) Citizenship	Romania	32	100
0 c) Age	12 14 15 16 17	3 5 8 6 10	9 17 25 19 31
0 d) Applied miniatures	Doppler Effect Double Cone Mini-wing Young's Double Slits Molecule Movement	6 6 6 7 7	19 19 19 22 22
0 e) Did you know in advance, that the lesson today would be a special self-guided one with computer-assisted miniature exhibits?	Yes No In between	11 14 7	34 44 22
1.Did you look forward to the lesson?	Yes No In between No answer	28 0 2 2	88 0 6 6
1.1 Reasons why not:	Preferation of other subjects (arts)	1	3
1.1 Reasons why yes:	Innovations Fun Contact with experts	14 13 3	44 41 9
2.Expectations	Advertisement for university Something extraordinary Easier theory No answer	1 16 23 5	2 36 51 11

3. Did the lesson come up to your expectations?	Yes No In between No answer	27 0 2 3	84 0 6 9
4. Did the lesson raise your interest in science?	Yes No In between	28 - 4	88 - 12
4.1. Reasons why not:	No answer	32	100
4.2. Reasons why yes:	Different way of learning Interactive approach Easier theory Something extraordinary	8 12 12 14	17 26 26 30
5. Most positive aspects of this learning scenario	Real objects Practical oriented Enough time IBSE Multimedia	14 25 3 4 6	44 78 9 13 19
6. Problems concerning the usage	Yes - technical No In between	5 27 -	16 84 -
7. Are you satisfied with the lesson?	Yes No In between	32 - -	100 - -
7.1 If not: Improvements	-	-	-
7.2 If "yes": What did you like?	Real objects/experiments Different to everyday school Multimedia Student-centred learning Contact with experts Fun Innovations	11 7 6 11 16 4 7	18 11 10 18 26 6 11
8. Any comments	-	-	-

Table 5.6: *Summarizing content analysis of interviews conducted during the workshop with students (school) in pilot phase A according to Mayring (2008). The categories to which the original answers to the interview questions were summarized are shown. Multiple nominations were possible.*

Suggestions for Improvements

Suggestions for improvement were summarised to optimise the revision of the SCeTGo suitcase and to improve each miniature and the corresponding scenarios developed (Table 5.7).

Doppler Effect Experiment:

- It is not easy to understand that the actual frequency emitted doesn't change. I would expect to see both what frequency the source emits and what the frequency the receiver perceives.
- The sound is horrible; I would prefer the single tone sound.
- The Sound stays behind movement.

Double Cone Experiment:

- The whole system needs a few moderations so it can be steadier.
- I didn't understand the maths/ physics behind it.
- The miniature is very abstract (should be connected to real world).
- It requires too high physics. The mathematical background is to complicated.
- The double cone can be adapted to lower secondary school by deleting the trigonometric formula.
- The angle calculation should be more accurate.
- The model should be bigger.
- The formula may confuse students.

Mini-wing Experiment:

- I didn't find the bridge between eyes and ears, I need more explanations.
- The exhibit is too difficult to explain in a meaningful way.
- What is the model behind it? What are the arrows for?
- The direction of the wind flow should be shown.
- More variation, different wing shapes should be provided.
- What is the optimum angle for rising.
- How did they model this?
- Better visualisation.

Young's Double Slits Experiment:

- Phenomena behind the equipment are quite hard to understand (if you are not a physical teacher for physics).
- I would expect to be able to see all three cases (photons, electrons and marbles), be able to change the distance between the slit and between the double slit and the screen. I would also like to change colours so the students would be able to make some calculations instead of just playing with the exhibit.
- I wasn't happy with the screen showing the mathematical formula.
- It is just a mathematical representation.
- Different colors should be used.
- What is the context to real life (too abstract)?
- Use different obstacles.
- View angle (behind, up).

Molecule Movement Experiment: • Better appearance of the heat source etc. • Bigger temperature differences, molecules could change colors. • Molecules doesn't move right all the time • Movement should be more fluent. • Temperature could be shown on the screen. • Thermometer didn't work accurate.
Suggestions for new experiments: • buoyancy, central force, rotation moment • geography, weather (how clouds and rain forms) • gravity, conductance, magnetism, biology (circulation of blood) • sound waves while speaking • structure of atoms and molecules • chemical compounds • states of water, surface tension • gravitation • how the light reflects from mirror

Table 5.7: *Suggestions for improvements of the SCeTGo systemç*

SCeTGo Suitcase Revision

Based on the results of the validation and the feedback given in phase A (Table 5.8), the SCeTGo suitcase was updated for phase B. Miniatures were revised and improved and an update of the software was carried out. Improvements conducted are summarized in note form in Table 5.8.

Doppler Effect Experiment: • Screen showing scale factor and additional data to allow students to calculate with the numbers have been added, formula has been included. • Exchange of microphone with a virtual person (has been changed back, since person was hard to recognize).
Double Cone Experiment: • New cones were printed to allow for colour coding. • Parameters are shown on the screen.
Mini-wing Experiment: • New wing types cylinder and plate were added. • Cylinder were supplemented as a third wing shape. • Drag arrow were changed to point backwards. • Fan was integrated to control airflow. • Molecules have been added to the fan. • Airplane has been added to the Augmented View.

Young's Double Slits Experiment: • Tangible model was changed to improve tracking and stability and to allow the slits to be set in different positions • Electron canon to bridge the gap from the particles to waves was added (before that there were two separated exhibits (balls and waves). They were merged to one exhibit which consists of balls, electron canon and waves. • In Version A the slit could be brought in three different distances to the back screen, in version B it is freely movable.
Molecule Movement Experiment: • Boltzmann graph "Molecule Movement" added. • New Fridge model has been created (old one caused problems with tracking). • Markers were improvements for better tracking stability (markers were heavily used since kids needed to touch them).

Additional changes made:
• Markers were improvements for better tracking stability (markers were heavily used since kids needed to touch them).
• Inlay was adapted due to new models.
• Software was updated:
    • Help files were updated.
    • Video was updated.
    • Exhibit Selection UI, installer and updater were updated.

Table 5.8: *Revision of the SCeTGo suitcase after implementation phase A*

5.4.3 Phase B: Quantitative Research

In the implementation phase B of the SCeTGo project (01/02/2011 – 01/12/2011) we included science museum staff (Heureka, Finland) and researchers of the participating organizations (universities and schools), as well as university students. We presented revised miniatures with the corresponding learning scenarios in the validation events (see 5.2.2).

Survey of Science Teachers (formal learning settings)

In the framework of different implementation events (see chapter 4) we introduced the SCeTGo system to 9 Swedish, 20 Spanish, 17 Greek, 19 Romanian and 3 Finnish science teachers. All together 68 science teachers filled out the questionnaires (gender: female 41, male 27; average age: 26.8, range: 23-60 years). Results are presented as follows.

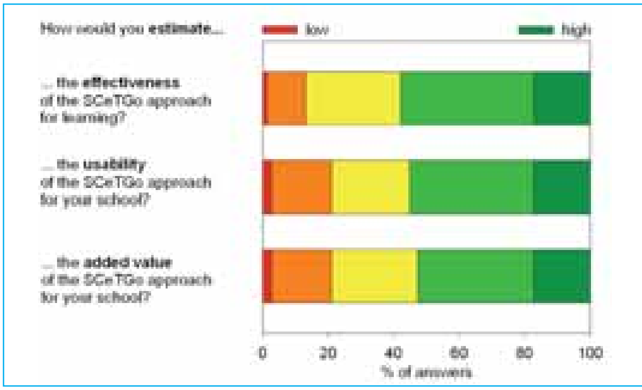


Fig. 5.17: Evaluation of Pedagogical Aspects I (VALNet)

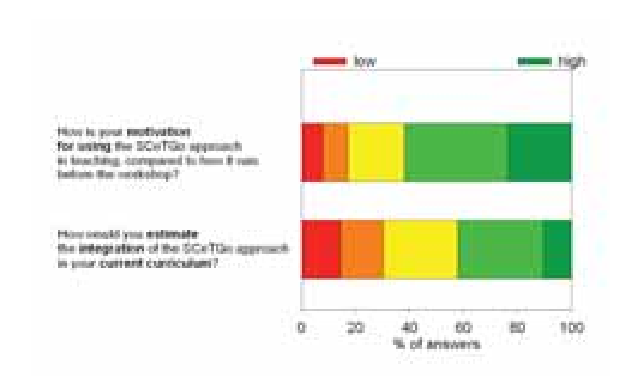


Fig. 5.18: Evaluation of Pedagogical Aspects II (VALNet)

Fig. 5.17 demonstrates that over 50% of the teachers estimated the effectiveness for learning, the usability for the school and the added value for the school in relation to the SceTGo approach at a high level. In addition, a less amount of teachers pointed out that the SceTGo approach was effective, usable and adding value at an average level. Furthermore, only a minority estimated the effectiveness for learning at a low level (15%). Moreover, the usability and the added value were assessed as low only by a very small amount of teachers (<3%).

As shown in Fig. 5.18, the motivation for using the SceTGo approach in teaching, compared to how it was before the workshop, was assessed as high by the majority of teachers (62%). Futhermore, 21% were motivated at an average and not even 20% of the teachers considered that their motivation was low (17%).

Although the motivation for using the SceTGo approach was highly valued, the integration of it in the current curriculum was estimated to be low by nearly one third of the teachers (30%). However, it was estimated at a high level by 42% and another 28% stated that it was integrated at an average.

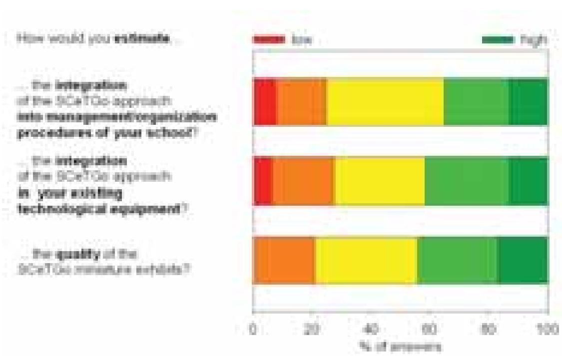


Fig. 5.19: *Evaluation of Technological Aspects (VALNet)*

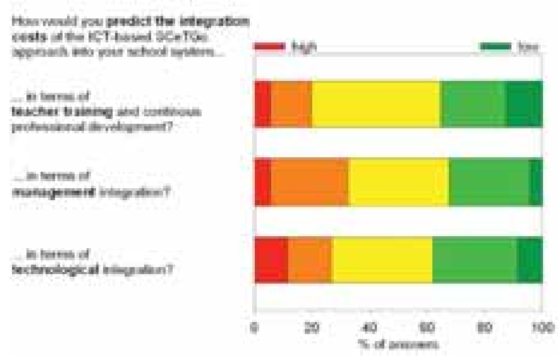


Fig. 5.20: *Evaluation of Economical Aspects (VALNet) I*

Fig. 5.19 illustrates that opinions about the integration of the SceTGo approach into management/organization procedures of the respective school varied. Over one third of teachers valued it to be high (35%), 40% pointed out that it was integrated at an average level and it was shown by further 25% that the integration of it was rated to be low. Comparing it to the integration in the existing technological equipment, more teachers estimated it to be high (42%). Furthermore, Fig. 5.19 shows that another 31% of teachers thought it was fairly integrated in the existing technological equipment. In addition, 27% of teachers stated that the integration in the existing technological equipment was low. In contrast to the latter estimations about integration, the estimated quality of the SceTGo miniature exhibits was highest (44%) in this part of the evaluation. In addition, a considerable amount of teachers assessed the quality at an middle rate (35%). Moreover, no interviewee stated the quality to be very low, only 21% estimated it to be of lower quality.

As it is confirmed by Fig. 5.20, most of the teachers predicted that the integration costs in terms of teacher training would be at an average level (45% of teachers). Furthermore, one third of teachers predicted these costs to be low (35%) and the smallest amount of interviewees forecasted that the costs would be high (20%). In terms of management integration, the costs were predicted to be low by 32%. Moreover, 35% of teachers pointed out that costs concerning management integration would be at a middle rate, whereas another third of teachers said they would be high (32%). In terms of technological integration, the pattern is similar to the previous one. The highest percentage of teachers predicted the costs to be low in this case (38%). In addition, 27% stated that the costs concerning technological integration would be high. All in all, the results were similar to each other and show only fractional differences which indicates that opinions about integration costs differ and that the interviewees do not have definite notions about this issue.

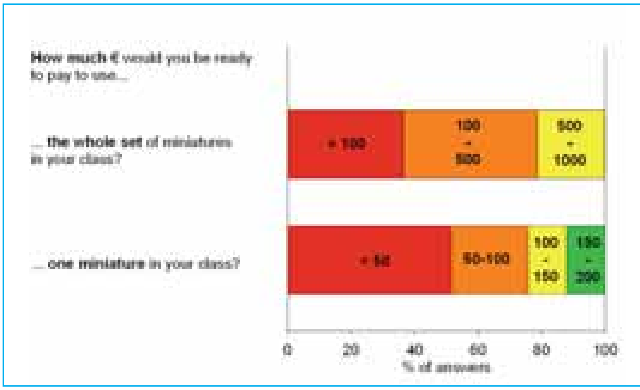


Fig. 5.21: *Evaluation of Economical Aspects II*

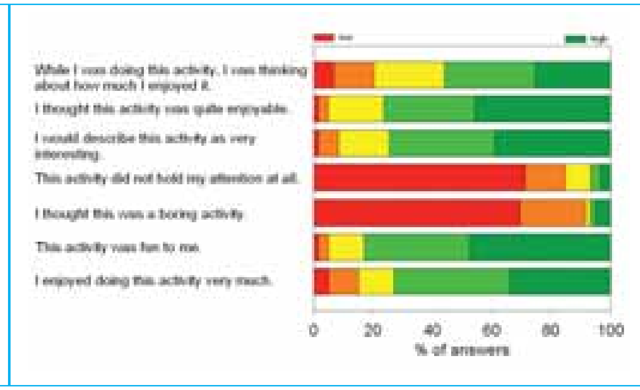


Fig. 5.22: *Evaluation of Interest/Enjoyment (Intrinsic Motivation Inventory)*

As shown in Fig. 5.21, most of the 33 teachers would spend 100-500 € for the whole set of miniatures in order to use it in their class (42%). A similar amount, however, would not pay more than 100 € for the whole set (36%). Furthermore, least teachers would spend 500-1000€ for the whole set (21%). For one miniature, over the half of them would not pay more than 50 € (52%). Moreover, 24% of teachers would spend between 50-100 €. In addition, an equal number of teachers would pay 100-150 or 150-200 € (12%). Due to a mistranslation only 33 teachers answered this question.

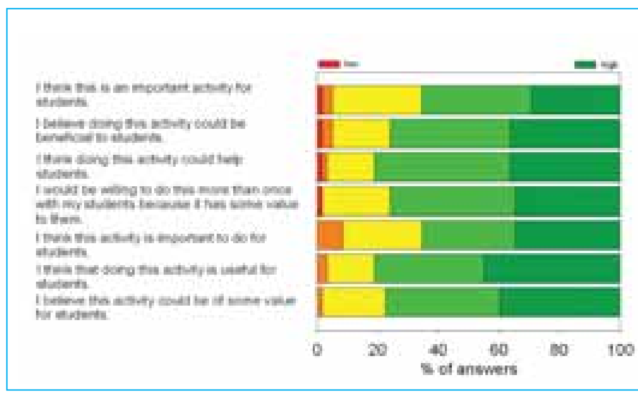


Fig. 5.23: *Evaluation of Value/Usefulness (Intrinsic Motivation Inventory)*

As it is shown in Fig. 5.22, the majority of teachers enjoyed doing the activity or thought it was interesting. To specify this, 46% of teachers highly enjoyed the activity; additionally, 31% enjoyed it much. The same results were shown when teachers were asked if they found the activity boring. In this case for example, 71% did not think that the activity was boring at all. Due to a mistranslation only 59 teachers answered this question.

As Fig. 5.23 demonstrates, the huge majority of teachers evaluated the activity positively. Thus, 45% of the teachers, for example, pointed out that the activity is very useful for students. In the same case, 36% stated that they found it useful. Furthermore, between 16% and 29% rated the activity positively at an average level. In addition, only a very small amount of teachers evaluated the activity negatively (2%-5%). Due to a translation error only 59 teachers answered this question.

In summary the quantitative results of teachers` evaluation in phase B a very satisfying.

Survey of Educators (informal learning settings)

In addition to teachers and students we also validated workshops with experts in the field of IBSE from the Heureka science centre. 22 member of the science center staff filled out the questionnaires (gender: 13, 5; average age: 37, range: 21-57 years). Comparable to the teachers` questionnaires we administered the VALNet subscales for pedagogical, technological and economic aspects and the subscales Value/Usefulness and Interest/Enjoyment of the Intrinsic Motivation Inventory.

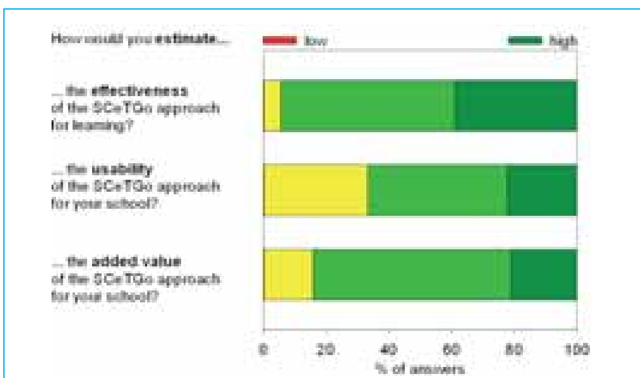


Fig. 5.24: Evaluation of Pedagogical Aspects I (VALNet)

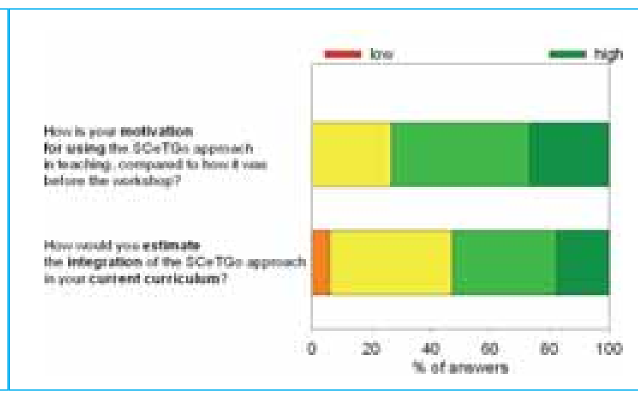
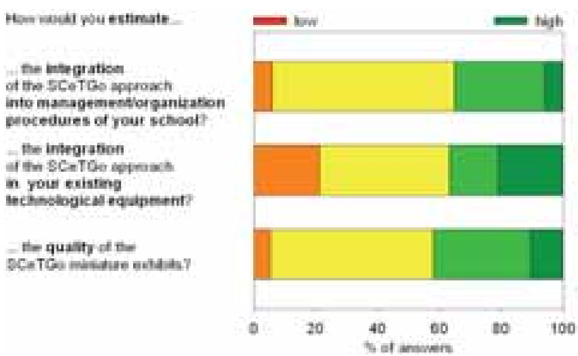


Fig. 5.25: Evaluation of Pedagogical Aspects II (VALNet)

Concerning pedagogical aspects (Fig. 5.24 and Fig. 5.25), the majority of educators rated the SCeTGo approach as very positive. This refers for example to its effectiveness for learning, its usability and value for their schools. Most of the educators are more motivated after the workshop than before to use the SCeTGo approach, and that half of them think positive about an integration it in the curriculum. Thus, the pedagogical aspects of the approach were evaluated in a very satisfying way, indicating that experts, similar to teachers, consider the approach to be pedagogical valuable.



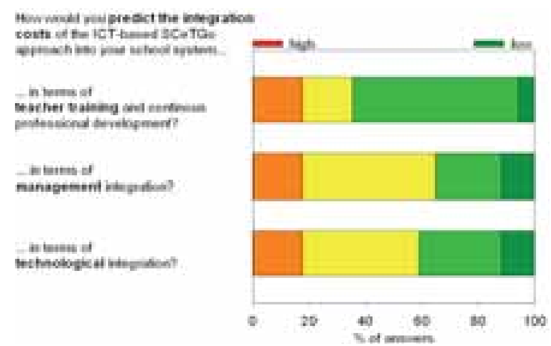


Fig. 5.26: *Evaluation of Technological Aspects (VALNet)*

Fig. 5.27: *Evaluation of Economical Aspects (VALNet) I*

Fig. 5.26 indicates that there are mostly seen only medium chances for integration of the SCeTGo approach into management/organization procedures of the school and in the existing technological equipment. The quality of the SCeTGo miniature exhibits was seen also mostly medium.

Most of participants predicted the integration cost the of ICT-based approaches into their school system as low or medium (Fig. 5.27). Management integration and technological integration is estimated to be higher than costs in terms of teacher trainings.

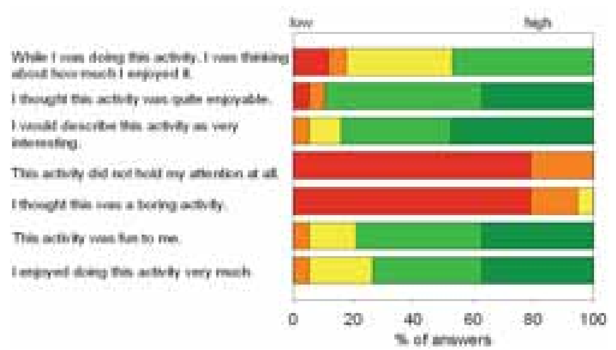


Fig. 5.28: Evaluation of Interest/Enjoyment (Intrinsic Motivation Inventory)

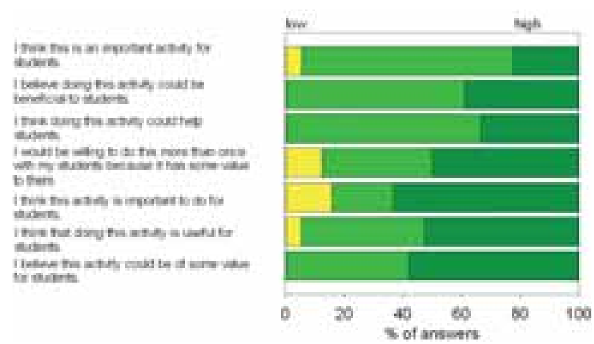


Fig. 5.29: Evaluation of Value/Usefulness (Intrinsic Motivation Inventory)

Furthermore, the majority was very satisfied with regard to interest and enjoyment (Fig. 5.28) which is also in line with the results of the teachers.

Every participant estimated the effectiveness as well as the usability and the added value of the SCeTGo approach high or at least medium (Fig. 5.29). Most of the participants thought, that this activity is useful and important for students. Only a few had an medium opinion, a negative answer was not given.

Survey of Students (school & university)

In Phase B the students' evaluation was divided in two groups divided by age. The first group consists of 97 school students (64 male, 31 female) in average 15 years old from Romania and Sweden. The second group comprised 200 university students, they were in average 24 years old and participated in SCeTGo validation events in Finland and Greece.

A comparison of these two groups is very interesting and important for our project as it covers the whole age range of students we are interested in.

All in all we can say according to the evaluation results that the SCeTGo miniatures are appropriate for both age groups. The complete evaluation results are shown in the Appendix. In this chapter of the report we point out the most meaningful evaluation results, figures presenting interesting aspects are shown.

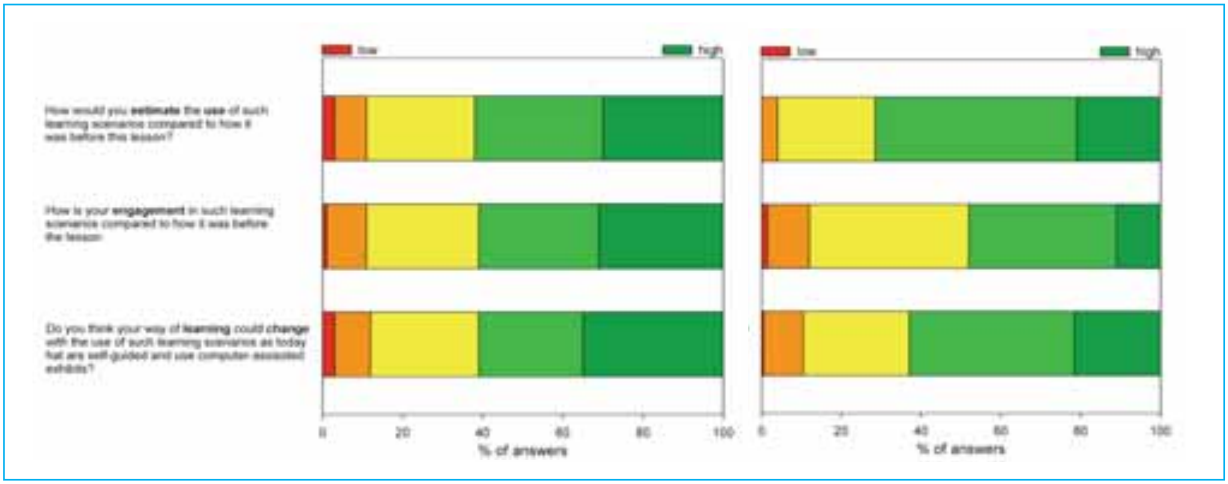


Fig. 5.30: *Evaluation of Pedagogical Aspects I (VALNet); left: students (school), right: students (university)*

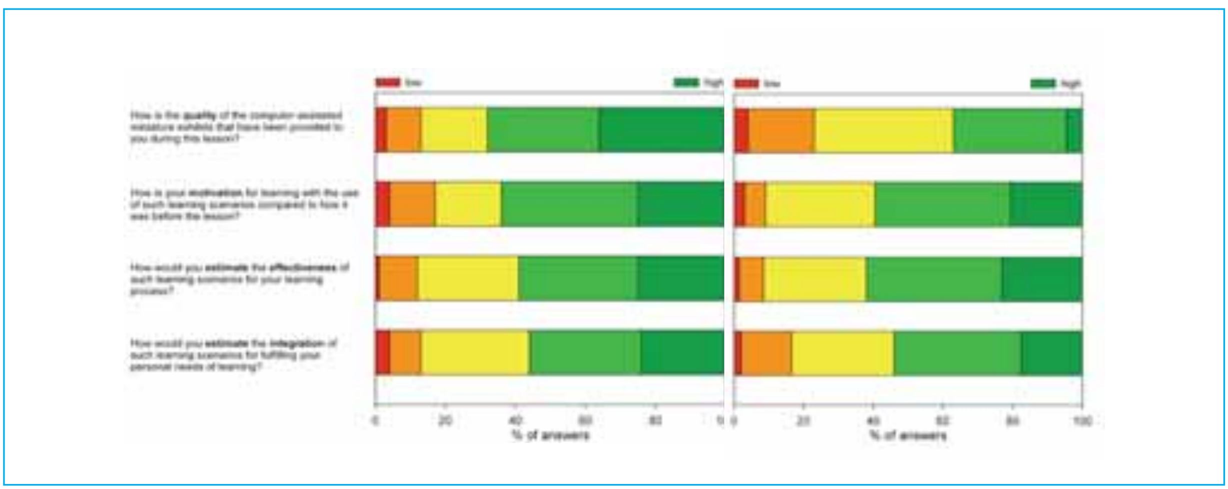


Fig. 5.31: *Evaluation of Pedagogical Aspects II (VALNet); left: students (school), right: students (university)*

In both groups more than 60% enjoyed learning with the SCeTGo miniatures and found them fascinating (see appendix). Interesting for the SCeTGo approach is that 51% of the younger students and 59% of the older ones (totally) agreed to the aspect that they like challenging tasks. This means that independent from age and cognitive development students like the SCeTGo pedagogical approach of inquiry based learning. This is an appropriate pedagogical method which is suitable for motivating students and raises their interest in science. In line with that around 60% of the students reported that their way of learning could change by the use of such learning scenarios and by self-guided and computer assisted exhibits. The lesson the students participated is important as the students say that they use and get engaged in that learning scenarios after the lesson more than before.

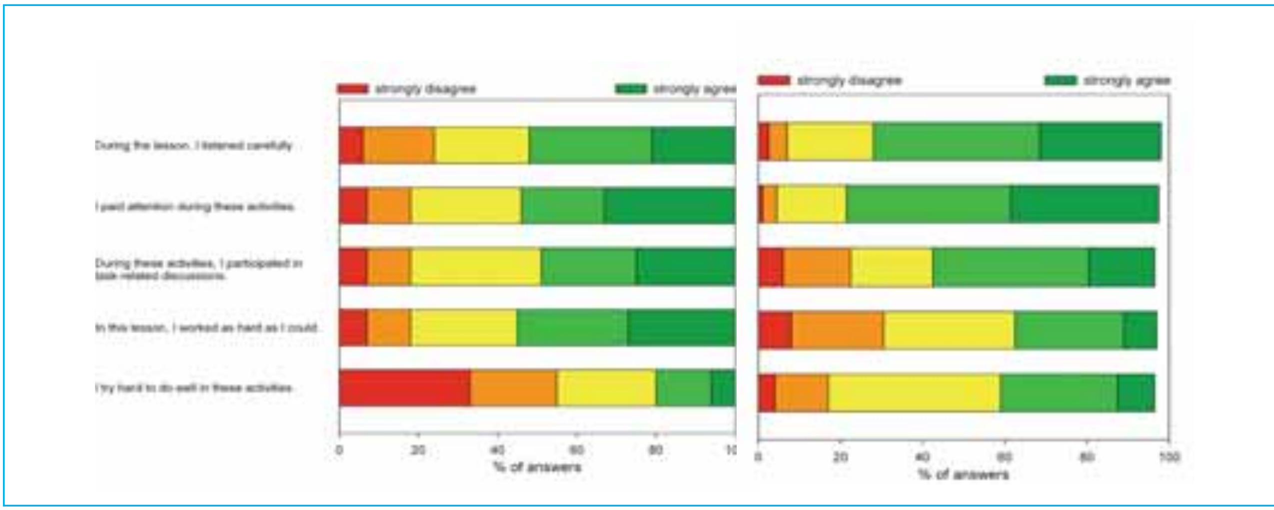


Fig. 5.32: Evaluation of Behavioral Engagement (Student Engagement Questionnaire);
left: students (school), right: students (university)

Comparing the results of behavioural tendencies during the lesson the age difference is the most important parameter for the results (see Fig. 5.32). The younger students listened more careful (52%), paid more attention (54%) and worked harder (56%) than the older ones (60%; 76 %; 34.5 %). The older students, however, tried harder to do well (37.5 %) and discussed more during the activities (54 %) than the younger ones (21%; 50%). However results could also indicate that younger students set more values to positive answers with regard to a social desirability.

5.4.4 Phase B: Qualitative Research

Survey of Teachers (formal learning settings)

Teachers interviewed in the implementation phase B (Table 5.9) came from Greece (25%), the UK (25%), Spain (17%), Austria (17%), Hungary (8%) or Romania (8%). Most of them were between 25 and 45 years old.

The majority of teachers were male (75%) only 25% were female. Most of them answered that they taught physics (35%) followed by mathematics (24%). Another 12% of the answers was related to the subjects chemistry, astronomy. Also 12% were teacher trainers. In addition, 6% of the answers pointed out that the teachers interviewed taught computer science.

Most of the interviewees were upper secondary or highschool teachers (67%). Furthermore, 25% answered that they were inferior secondary (gymnasium) teachers and an minority of 8% stated that they taught in primary school. In most answers it was mentioned that teachers took notice of the SCeTGo workshop either via e-mail, or due to the pathway project, or because they were part of the summer schools' program or took part at a teacher training course (15% each). Concerning expectations about knowledge, attitudes, and values most answers were related to the application to a new interactive didactic tool (33%). In further 25% of the answers is was pointed out that teachers wanted to know how to use AR in school activities. In addition, 17% of the given answers referred to the understanding of the usage.

Most teachers answered that the SCeTGo workshop came up to their expectations concerning knowledge, attitudes, and values (67%). No answer stated that anyone was discontent. Additionally, 33% of the answers referred to the fact that some teachers' opinions were in between 'yes' or 'no'. Most of the answers showed that teachers were motivated to use the SCeTGo approach in future lessons (83%). As the answers showed, most convincing concerning the usage of the SCeTGo approach were that it was a hands-on approach, it demonstrated abstract phenomena, that the miniatures helped with teaching, that it was easy to handle, and that it offered a great visualization (15% each). Teachers who were undecided about their motivation to use the SCeTGo approach in their future lessons explained that the approach was still in an early implementation phase (33% of answers).

The most positive aspects of the SCeTGo approach were that it augmented reality, that it had an edutainment-approach and that it visualized the invisible (14% each). 75% of the answers given showed that the teachers had no problems understanding the usage of the SCeTGo exhibits. Most teachers were satisfied with the SCeTGo workshop (67%). Nobody answered that they were discontent. A huge amount of answers referred to the fact that teachers liked the good teaching approach (44%) and that it was easy to use (22%).

Parts which could be enhanced in future workshops were, for example, to have discussions for improvements, a better link between the miniatures and the inquiry methodology of learning, and better/ more explanations and introductions.

Interview Questions	**Categories**	**Workshop Validation**	
		Number of answers	**%**
Gender	Male Female	9 3	75 25
0 a) Subjects I'm a physics teacher and I have a master degree in astrophysics.	Mathematics Physics Chemistry Astronomy Computer Science Teacher trainer	4 6 2 2 1 2	24 35 12 12 6 12
What level do you teach:	Primary Inferior secondary/ gymnasium Upper secondary/ highschool	1 3 8	8 25 67
b) Citizenship	Hungary Greece Romania Spain UK Austria	1 3 1 2 3 2	8 25 8 17 25 17
c) Age	25 – 30 30 – 35 35 – 40 40 – 45 45 – 50 50 - 55 55 - 60	2 2 4 2 1 0 1	17 17 33 17 8 0 8
d) Applied miniatures	mini-wing mini-firetruck mini-cooler & heater all miniatures applied	6 6 4 5	29 29 19 24

1. How did you take notice of the SCeTGo workshop?	Teacher informed me Teacher trainer informed me Personal interest E-mail Due to the pathway project Part of summer schools' program Part of the course "Innovation and introduction to educational research in physics and chemistry"	1 1 1 2 2 2 2	8 8 8 15 15 15 15
2. What have you expected from the SCeTGo workshop, concerning knowledge, attitudes, and values?	To know how to use AR in school activities Application to a new interactive didactic tool Understanding the usage To see how the connection between inquiry based science education and a augmented reality technology works A wider understanding of the use of Information and communication technology in the classroom.	3 4 2 1 2	25 33 17 8 17
3. Did the SCeTGo workshop come up to your expectations, concerning knowledge, attitudes, and values?	Yes No In between	8 0 4	67 0 33
4. Are you motivated to take use of the SCeTGo approach in your future lessons?	Yes No In between	10 0 2	83 0 17
If "yes": What exactly convinced you, to make use of the SCeTGo approach?	Hands-on approach Demonstrate abstract phenomena Miniatures help with teaching Superior to books Easy handling Simple model of reality Great visualisation Undemanding integration in lesson plan	2 2 2 1 2 1 2 1	15 15 15 8 15 8 15 8
If "no": Please mention the reasons, why you don't want to make use of the SCeTGo approach!	Only useable for physics, miniatures for biology etc. are missing Time consuming Not very versatile (it doesn't allow the teacher to add up/modify/adapt its contents) Still in an early implementation phase Evidence of its usefulness is missing	1 1 1 2 1	17 17 17 33 17

5. What do you think are the most positive aspects of the SCeTGo approach?	Augmented reality Edutainment - approach (adaptive software, you can play with) Easy to understand Visualisation of the invisible Use of new technologies in school If it is accessible, it could be cheap Useful tool for science teaching Interaction with the experiments Combination between physical objects with virtual animations Easy to use The inquiry-based learning methodology	2 2 1 2 1 1 1 1 1 1 1	14 14 7 14 7 7 7 7 7 7 7
6. Is there something you didn't understand, concerning the usage of the SCeTGo exhibits?	No It was clear; but I still feel uncomfortable to use the software Need more information (Where can I buy it? How do I use it?) How exactly could I to use it in the classroom	9 1 1 1	75 8 8 8
7. Are you satisfied with the SCeTGo workshop?	Yes No In-between	8 2 2	67 0 17
If "yes": What did you like?	Good teaching approach Nice demonstration Suggests future of teaching Very engaging Easy to use	4 1 1 1 2	44 11 11 11 22

8. Any comments? Recommendations for improvements: • I just got a presentation, which I can get off the website. There was no feedback. • Discussions for improvements were missing. • I would have liked to see more clearly how these miniatures are related to the inquiry methodology of learning. • Miniatures are so far only prototypes • More explanations/theory • Better introduction, especially of how to use in the class. • More and longer practical parts. • The project should allow teachers to actively participate in the design process of new experiments. • Too much time is needed to perform the experiments with the SCeTGo miniatures, whereas teachers usually have a tight schedule. • There are cheaper ways of doing Inquiry-Based Learning activities with students. • I would be afraid of wasting time adjusting the camera. • The SCeTGo proposal needs further development in order to be used in the classroom. • It seems that teachers can't adapt the minatures to their specific needs. • They are OK for lower class levels, but for higher they need to be improved, for example for university students. The whole model should be implemented for older kids. • The sessions were very time consuming. • No information of the availability was given. I am not aware if it is possible to purchase such a kit at all.
Positive comments: • I would like to know more, in general. • A new method, wanted to see how these demonstrations work in real life and not just on the internet since I have already seen this. • Create more miniatures, for example for biology, especially in the lower price categories. • I would like to attend more of these workshops. • I admire people who develop these kits. • The workshop also made me think about the technical difficulties that would imply to train teachers on the use of the tool. • I would like to know more and see examples of the methodology in which these experiences are based. • I have a basic idea of what it is. • It was very interactive. • I will make use of the technology. • I got what I expected, easy to use and quick to use packages. • The homepage has enough information in order to use it. • The Inquiry-Based Learning methodology can engage students. • The SCeTGo experiments are easy to perform. • The miniatures are well-thought and original. • You can actually use and manipulate the exhibits and play for yourself, very easy to use, anybody can use it.

Table 5.9: *Summarizing content analysis of interviews conducted during the workshop with teachers in pilot phase B according to Mayring (2008). The categories to which the original answers to the interview questions were summarized are shown. Multiple nominations were possible.*

Survey of Projects` Partners

Table 5.10 shows the results of the project partner's evaluation of the SCeTGo.

The SCeTGo consortium comprises experts from different areas of information technology, but also expertise in didactics and pedagogy. Participants interviewed came from Finland, Romania, Spain, Sweden, 21% Greece and Germany. 43% of 14 participants interviewed have been female, and 57% were male.

All 14 interviewees confirmed that the project came up to their expectations, concerning knowledge, attitudes and values. Furthermore all of them said "yes" when they were asked whether they were motivated to use the SCeTGo in the future. Several different reasons for the approval were mentioned. 30 % said they believed the SCeTGo provided a good hands-on approach to various phenomena. In the same context 12% thought that this way of learning was overall better and more important than getting information out of books. Another 30% praised the easy handling of the experiments. Two of the interviewees believed that the SCeTGo helps to better understand complex and abstract phenomena. It was also mentioned that miniatures can be very useful in teaching. 18% of the questioned said it was a great option for visualising processes which are normally invisible. Although the project partners were basically motivated to take use of the SCeTGo, a few of them also believed there could be made some improvement. One person said the tools should be developed further while another interviewee stated that some of the phenomena could be hard to understand. When asked about the most positive aspects of the project, two of the interviewees mentioned the practical approach to a complex phenomenon. Four of the project partners believed that the best aspect of the SCeTGo was the help in understanding it provided. Two people valued the opportunity of a nice demonstration as most significant. A big number of the project partners (33%) considered the visualisation of invisible phenomena as one of the most positive aspects of the SCeTGo. Two further advantages mentioned were the use of new technologies in school and the better corporation between school and research made possible by the SCeTGo.

Most of the project partners (71%) did not have any difficulties in understanding the usage of the SCeTGo exhibits. Two interviewees believed they still needed to learn how to use the tool properly. One of the questioned had a few technical concerns while another person found it difficult to connect new and old conceptions.

The project partners were also asked whether they were overall satisfied with the workshop. 93% answered "yes" while one person settled between "yes" and "no". None of the interviewees were entirely dissatisfied with the SCeTGo. When they were questioned about the reasons for their approval the project partners mentioned again the ease of use (29%), the great opportunity for practical demonstrations it delivered (7%) and the way it makes teaching easier (14%). 21% stated they were impressed by the tool and it's technology. 14% thought the SCeTGo was generally a great idea while another 14% believed the experiments were easy to understand. Furthermore the interviewees were asked about aspects they would like to see improved. One person believed that some of the miniatures were too abstract while another one of the interviewees stated that the miniatures were only prototypes so far and needed further development. Other points mentioned were the needed improvement of the instructor's knowledge (20%) and the necessity of making own experiences (20%). One of the interviewees stated that the demonstrations should be longer.

Concluding, the interviewees were asked about further comments on the workshop. Some of the project partners said they were looking forward to using the SCeTGo system in the future. One person expressed their wish that you could get more information from the exhibits "so the students [...] have something to work with". Other comments basically have been mentioned before.

Interview Questions	Categories	Workshop Validation	
		Number of answers	%
Gender	Male Female	8 6	57 43
0 b) Citizenship	Finland Greece Romania Spain Sweden UK Germany	2 3 2 1 2 2 2	14 21 14 7 14 14 14
0 c) Age			
0 d) Applied miniatures	All miniatures were applied (Doppler Effect, Double Cone, Mini-wing, Young's Double Slits, Molecule Movement)	14	100
1. How did you take notice of the SCeTGo workshop?	-	-	-
2. What have you expected from the SCeTGo workshop, concerning knowledge, attitudes, and values?	Interesting and basic knowledge Application to a new teaching form Understanding the usage Great tool for pupils	3 11 2 1	18 65 12 6
3. Did the SCeTGo workshop come up to your expectations, concerning knowledge, attitudes, and values?	Yes No In between	14 - -	100 - -
4. Are you motivated to take use of the SCeTGo approach?	Yes No In between	14 - -	100 - -

If "yes": What exactly convinced you, to make use of the SCeTGo approach?	Hands-on approach Demonstrate abstract phenomena Miniatures help with teaching Superior to books Easy handling To visualise the invisible	10 2 1 4 10 6	30 6 3 12 30 18
If "no": Please mention the reasons, why you don't want to make use of the SCeTGo approach!	Tools need more development Did not understand all phenomena	1 1	50 50
5. What do you think are the most positive aspects of the SCeTGo approach?	Practical approach Better understanding of complicate phenomena Nice demonstration Visualise invisible aspects of a phenomenon Use of new technologies in school Better cooperation between school and research.	2 4 2 5 1 1	13 27 13 33 7 7
6. Is there something you didn't understand, concerning the usage of the SCeTGo exhibits?	No Still have to learn how to use the tool Technical concerns Difficult to connect new and old conceptions	10 2 1 1	71 14 7 7
7. Are you satisfied with the SCeTGo workshop?	Yes No In-between	13 - 1	93 - 7
If "yes": What did you like?	Easy to use Impressive tool/ technology Great idea Good teaching approach Nice demonstration Easy to understand: 1	4 3 2 2 1 2	29 21 14 14 7 14
If "no": What should be enhanced in future workshops?	Longer demonstration Miniatures are so far only prototypes Instructors need more knowledge Some miniatures are very abstract. Have to make experiences by myself	1 1 1 1 1	20 20 20 20 20
8. Any comments? - No - Looking forward to use is it. - Some miniatures are very abstract. - Generally I would expect to get more info from each exhibit so the students could have something to work with. - Exhibits should be more accurate			

Table 5.10: *Summarizing content analysis of interviews conducted during the workshop with researchers of different fields of education, who are involved in the project in pilot phase B according to Mayring (2008). The categories to which the original answers to the interview questions were summarized are shown. Multiple nominations were possible.*

Survey of Students (school & university)

As already mentioned in the quantitative analysis (Table 5.4.3.) in phase B the students' evaluation was divided in two groups divided by age. The first group comprised university students that participated in SCeTGo validation events in Greece (Table 5.5.3). The second group consists of school students (named as pupils) from Sweden (Table 5.5.4). We compared both groups to covers the whole age range of students we are interested in.

In the younger group seven male pupils and one female pupil participated. All of them were in ninth grade, were 16 years old and came from Sweden. In comparison, the group of university students consisted of five men aged between 20 and 26 who were in their seventh semester at university and all came from Burundi (Africa).

With regard to the pupils, everyone applied every offered miniature (100%), which were the Doppler Effect, the Double Cone, the Mini-wing, the Young's Double Slits and the Molecule Movement. On the other hand, miniatures applied by the university students were the Doppler Effect (63%), the Mini-wing (25%) and the Molecule Movement (13%).

Interview Questions	Categories	Workshop Validation	
		Number of answers	Number of answers
Gender	Male Female	5 0	100 0
a) Grade/ Semester	7th semester (University)	5	100
b) Citizenship	Burundi (Africa) Greek	1 4	20 80
c) Age	20-26	5	100
0 d) Applied miniatures	Doppler Effect Mini-wing Molecule Movement	5 2 1	63 25 13
e) Did you know in advance, that the lesson today would be a special self-guided one with computer-assisted miniature exhibits?	Yes No	1 4	20 80
1. Did you look forward to the lesson?	Yes No No answer	2 1 2	40 20 40
1.1 Reasons why not:	No information	3	100
1.1 Reasons why yes:	Innovations Be informed about AR No answer	2 1 2	40 20 40

2. Expectations	To learn something new To learn about the underlying phenomenon	1 1 3	20 20 30
3. Did the lesson come up to your expectations?	Exceeded expectations Yes	1 4	20 80
4. Did the lesson raise your interest in science?	Yes	5	100
4.1. Reasons why not:	No answer	-	-
4.2. Reasons why yes:	Interactive approach Scenario, technology Practical approach, not only theory Connects science (theory) with technology	1 2 1 1	20 40 20 20
5. Most positive aspects of this learning scenario	Experimental hands-on activity Raises interest in the way it is used to present science AR representations Visualization of unseen properties Better understanding of phenomena due to a connection with reality	1 1 1 1 1	20 20 20 20 20
6. Problems concerning the usage	Yes - Graphical representation of waves No In between - I understood everything that was presented to me, but this fact raised more questions about the phenomena)	1 3 1	20 60 20
7. Are you satisfied with the lesson?	Yes	5	100
7.1 If not: Improvements	-	-	-
7.2 If "yes": What did you like?	Different to everyday practice Informal approach in a formal settlement AR representations Teaching method with innovative technology and multimedia	2 1 1 1	40 20 20 20
8. Any comments? • No • Looking forward to use is it. • Some miniatures are very abstract. • Generally I would expect to get more info from each exhibit so the students could have something to work with. • Exhibits should be more accurate			

Table 5.11: *Summarizing content analysis of interviews conducted during the workshop with university students in pilot phase B according to MAYRING (2008). The categories to which the original answers to the interview questions were summarized are shown. Multiple nominations were possible.*

Interview Questions	Categories	Workshop Validation	
		Number of answers	%
Gender	Male Female	7 1	88 22
0 a) Grade/ Semester	9	8	100
0 b) Citizenship	Sweden	8	100
0 c) Age	16	8	8
0 d) Applied miniatures	Doppler Effect Double Cone Mini-wing Young's Double Slits	8 8 8 8	100 100 100 100
0 e) Did you know in advance, that the lesson today would be a special self-guided one with computer-assisted miniature exhibits?	No	8	100
1.Did you look forward to the lesson?	Yes No No answer	4 3 1	50 38 13
1.1 Reasons why not:	No information	3	100
1.1 Reasons why yes:	Innovations Fun Contact with experts	2 2 1	40 40 20
2.Expectations	Advertisement for university Something extraordinary Easier theory No answer	1 3 1 2	13 38 13 25
3. Did the lesson come up to your expectations?	Exceeded expectations Yes No In between No answer	2 3 - 1 2	25 38 - 13 25
4. Did the lesson raise your interest in science?	Yes No In between	3 3 2	38 38 25
4.1. Reasons why not:	No answer	3	100
4.2. Reasons why yes:	Different way of learning Interactive approach	5 2	71 29

5. Most positive aspects of this learning scenario	Real objects Practical oriented Enough time IBSE Multimedia	3 5 1 2 5	19 31 6 13 31
6. Problems concerning the usage	Yes (technical) No	1 7	13 88
7. Are you satisfied with the lesson?	Yes	8	100
7.1 If not: Improvements	-	-	-
7.2 If "yes": What did you like?	Real objects/experiments Different to everyday school Multimedia Student-centred learning	2 3 1 2	25 38 13 25
8. Any comments? (Suitable for science learning, More usage in school, Future-oriented technology, Theory was too difficult)			

Table 5.12: *Summarizing content analysis of interviews conducted during the workshop with students (school) in pilot phase B according to MAYRING (2008). The categories to which the original answers to the interview questions were summarized are shown. Multiple nominations were possible.*

Most of the pupils looked forward to the lesson (50%) because they expected to learn about innovations (40%), to have fun (40%) and to have contact with experts (20%). Comparing them to the university students, less of the latter looked forward to the lesson (40%) but expected to learn about innovations equally to the pupils (40%). A second reason given by the university students was being informed about AR (20%). Furthermore, most of the pupils expected something extraordinary (37,5%). The other pupils who have given an answer to this question pointed out that they expected an advertisement for university (12,5%) or to get an easier theory (12,5%). The university students, on the other hand, gave different answers about their expectations. They expected to learn something new (20%) or to learn something about the underlying phenomenon (20%). Moreover, of all university students the interest in science was raised. However, to the pupils this applied only partially (37,5%). Pupils explained that their interest was increased because it was a different way of learning (71%) and because it had an interactive aproach (29%). The interactive approach was also mentioned by the university students (20%). Furthermore, the university students pointed out that their interest was increased because of the scenario and the technology (40%), because it had an practical and not only theoretical approach (20%) and because it connected science (theory) with technology (20%). Additionally, the most positive aspects of this learning scenario mentioned by the pupils were the practical orientation and the multimedia (31% each). Further aspects were that the learning scenario contained real objects (19%), the IBSE (13%) and that they had enough time (6%). In comparison, the university students gave different answers. For them, the most positive aspects were that it was an experimental hands-on activity, that it raised interest in the way it is used to present science, the AR representations, the visualization of unseen properties and that the phenomenon could be better understood due to a connection with reality (20% each).

5.5 Discussion

In the context of SCeTGo AR is used for educational purposes as a computer-mediated learning system that aims at the integration of AR technology in science teaching. Thereby, SCeTGo provides an augmented visualization aid for education.

However, in recent years technology enhanced teaching systems were questioned considering their learning efficiency. Ardito et al. [12] demanded "a synergy between the learning process and a student's interaction with the software." Furthermore " usability features should not only allow people to efficiently manipulate the interactive software, but should also be appropriate for the intended learning task." The purpose of WP5 Validation & Quality Assurance was to get an insight in the educational value of the SCeTGo system as an AR technology for students and teachers in order to ensure utilization in classrooms.

First of all we will present a summary of students and educators feedback with regard to the pedagogical effectiveness, based on these results we will validate if the objectives of the project are achieved (see chapter 2.1). Subsequently, we will focus on the usability of the SCeTGo approach, because teachers` validation could show that a user-friendly design is an important pre condition for the acceptance of the SCeTGo system.

5.5.1 Students` Validation of Pedagogical Effectiveness

Pedagogical effectiveness was rated by students with regard to an increase in interest in natural science and enjoyment of the lesson. Overall, the feedback given by pupils within the individual interviews was mostly positive.

According the data students really liked working and learning with the miniatures. They did not suggest any improvements. In particular, the hands-on approach of the miniatures, the student-centered lessons and the multimedia aspects was accentuated. The high percentage of interested students shows that most of them were inspired by the exhibits and the AR technology. Furthermore students mentioned that the SCeTGo experiments facilitates the understanding of physical phenomena.

5.5.2 Educators` Validation of Pedagogical Effectiveness

Teachers as well as educators from other fields of education from different countries evaluated SCeTGo and mentioned positive and negative aspects of the approach.

They evaluated the miniatures in combination with an AR technology as a valuable tool for instruction. Educators positively emphasized the interactive visualization by placing additional information (e.g. invisible molecules) into real surroundings. It simplifies the explanation of abstract phenomena as abstract phenomena are shown figuratively. Thus young people's interest in science is reinforced. The SCeTGo approach was evaluated positively, as it allows the learner to interact dynamically with the miniature exhibits and fosters hands-on activities.

An active participation of the learner during the learning process is regarded as a basic prerequisite for acquiring knowledge [13]. The qualitative analysis revealed that SCeTGo simplifies instruction, what implies that miniatures have a high value to teachers.

Furthermore teachers mentioned that key competences are developed, not only in science, but also with regard to technological skills.

5.5.3 Validation of Projects` Objectives

1. **Does the SCeTGo approach raise interest in science and science motivation?** Yes. Especially students evaluated the SCeTGo approach positive.The application of the SCeTGo miniatures raised students` interest and activated the majority of participants to get more involved in science contents. It therefore could engage students to get more interested in science in general.

2. **Does the SCeTGo approach reach to induce engagement of students in experimental science learning?** Yes. The highly scored interest of participants to engage in such experimental exhibits and their learning contents are satisfyings. This additionally affirms the aimed pedagogical concepts of the SCeTGo project. Especially teachers as well as students positively emphasized the interactive visualization by placing additional information (e.g. invisible molecules) into real surroundings. It was evaluated positively, as it simplifies learning and allows the learner to interact dynamically with the miniature exhibits. An active participation of the learner during the learning process is regarded as a basic prerequisite for acquiring knowledge [15].

3. **Does the SCeTGo approach lead to satisfying learning outcome, especially considering problem-solving and critical thinking skills?** Yes. Also learning outcomes were not assessed (see chapter 3.1).; the SCeTGo approach provides teachers with a tool in order to facilitate students' learning. Scenarios favor an inquiry based learning, especially this approach should support problem-solving and critical thinking skills.

4. **Does the SCeTGo approach offer teachers an enrichment of their everyday teaching practice?** Yes. The overall acceptance of the workshops seems to be high and miniatures seem to be user-friendly.The validation could support that the SCeTGo approach offers a modern science centre experience outside the walls of the science centre in school classrooms. This shows that the SCeTGo project has the potential to be applied in school environments and introducing AR into the classroom is in line with the needs of educators.

5.5.4 Validation of Usability

Validation could show that next to pedagogical effectiveness a user-friendly design is an important pre condition in order to ensure users `acceptance. Usability plays a central role to meet the requirements of teachers and students and to adapt the AR technology to the specific needs of school environments. However requirements with regard to usability differ between the user group (students) and the "provider" group (educator).

Balog and Pribeanu [3] for instance, had shown the perceived usefulness and the perceived enjoyment as relevant factors for students' acceptance of an AR application, while the perceived ease of use was not a significant precursor for students' acceptance. Still in contrast to students, teachers are standing in front of a class while using an interactive software system. Therefore, teachers require a user friendly software, they could fully rely on. Consequently Ardito and collegues [12] argued that from the point of view of people, who are applying an interactive software system, usability should be the most important aspect. With regard to usability features (technical demands, user-friendliness and handling) of the SceTGo approach most educators reviewed exhibits to be easy to handle. Especially a rapid prearrangement of the setup was pointed out as a positive feature.

With reference to technical acceptance usability, features are easy to operate and there are no real obstacles that teachers have to overcome in order to use the system. Yet, teachers mentioned that a system needs to be extraordinary flawlessly operational, in order to be usable at school – in some cases this was already demanded from the prototypes.

Results emphasize that an AR system like SCeTGo has to operate absolutely reliable in order to be integrated in teachers` instruction. Taking this into consideration, the SCeTGo technology still needs improvement to finally convince also critical teachers of its applicability. However, then the system verifies a successful future integration of exhibits based on AR-technology in instruction, which could be easily included in school lessons as long as they operate absolutely reliable.

5.5.5 Comparison of Pilot Phase A and B

The comparison of the qualitative and quantitative analysis of phase A and B shows that there has been a positive development of users' attitude towards SCeTGo. From the beginning students had a high opinion of the SCeTGo approach. Teachers were convinced of its usefulness, however still sceptical about the software. In phase B miniatures have been revised and scenarios have been added. Therefore not only pedagogical effectiveness, but also usability has been improved. The results of the analysis indicate that the handling and therefore the user-friendliness has improved in phase B. The high ratio of recommendations with regards to its educational efficiency reflects the positive attitude towards the SCeTGo system in general as long as the software run in a proper way.

5.5.6 Critical Remark with Regard to Teachers' Acceptance of AR

Science teachers play a crucial role for the implementation of AR technologies in school. Results indicate a high interest for new technologies and new learning/teaching strategies amongst teachers in school environments in general. Nevertheless participating teachers were not randomly chosen, since they selected the teachers training courses in order to get to know state-of-the-art technologies and to get new ideas for improvement of their instruction. Based on motivational reasons, it is not surprising that most of the participants are encouraged to use this approach further on. As workshop participation was an optional offer, it could be the case that teachers not interested in new technologies in general decided not to participate.

5.6 Conclusion

In summary projects objectives are achieved, students enjoyed working and learning with the miniatures and most of the teachers assessed pedagogical effectiveness as well as technological aspects throughout positive. SCeTGo proposes an inquiry-based approach with a learner-specific constructivistic idea of learning. It enriches the repertoire of learning offers to more innovative teaching methods due to an AR inclusion with the specific aim to improve quality of learning. Thereby, it brings AR enhanced learning experiences out of the science centre into a school classroom, by offering the experience of a modern science centre in school and thus crosscutting the boundaries between formal and informal learning. In conclusion, SCeTGo seems to be appropriate to integrate AR in schools and offers conditions to have an impact on education in long term.Thereby, through its implementation in schools an AR enhanced learning system, as SCeTGo contributes to a new form of education.

5.7 References

[1] Sotiriou S, Bogner FX: Visualizing the Invisible: Augmented Reality as an Innovative Science Education Scheme. Advanced Science Letters 2008, 1(1), 114-22.

[2] Salmi H, Sotiriou S, Bogner FX: Visualizing the Invisible in Science Centres and Science Museums: Augmented Reality (AR) Technology Application and Science Teaching. In: Karacapilidis N, editor. Web-Based Learning Solutions for Communities of Practice: Virtual Environments for Social and Pedagogical Advancement 2009, 185-210. New York: Information Science Reference.

[3] Balog A, Pribeanu C. The Role of Perceived Enjoyment in the Students' Acceptance of an Augmented Reality Teaching Platform: A Structural Equation Modelling Approach, Studies in Informatics and Control 2010; 19(3): 313-30.

[4] Bogen M, Wind J, Giuliano A. ARiSE - Augmented Reality in School Environments. In: Nejdl W, Tochtermann K, editors. Proceedings of European Conference on Technology Enhanced Learning; 2006 Oct 1-4; Crete, Greece. p. 709-14.

[5] Wind JK, Riege M, Bogen, Spinnstube®: A Seated Augmented Reality Display System. In: Fellner D, editor. Proceedings of Virtual Environments, IPT-EGVE - EG/ACM Symposium; 2007 Jul 15-18; Weimar, Germany. Aire-la-Ville: Eurographics Association; 2007. p. 17-23.

[6] Sotiriou S, Anastopoulou S, Rosenfeld S, Aharoni O, Hofstein A, Bogner F, Sturm H, Hoeksema K. Visualizing the Invisible: The CONNECT Approach for Teaching Science. ICALT 2006: 1084-10.

[7] Wittkämper M, Braun AK, Herbst I, Herling J. A Distributed System for Augmented Reality Experiences in Science Centres and Museums; Technologies for E-Learning and Digital Entertainment 2007; p. 936-46.

[8] Buchholz H, Wetzel R. Introducing Science Centre TOGO - A Mixed Reality Learning Environment for Everyone's Pocket; IADIS International Conference Mobile Learning 2009 (pp. 104-110), Barcelona, Spain 2009.

[9] Buchholz H, Brosda C, Wetzel R. Science Center To Go - A Mixed Reality Learning Environment of Miniature Exhibits. In Lazoudis, A. Sotiriou, S. (Eds) Proceedings of the "Learning with ATLAS@CERN" Workshops Inspiring Science Learning EPINOIA, 2010, ISBN Number: 978-960-473-219-7. pp. 85-96.

[10] Lamnek S. Qualitative Sozialforschung, Methoden und Techniken. Weinheim. Beltz Psychologie Verlags Union; 1995.

[11] Mayring P. Qualitative Inhaltsanalyse, Grundlagen und Techniken. Weinheim: Deutscher Studien Verlag; 1997.

[12] Ardito C, Costabile MF, Marsico M de, Lanzilotti R, Levialdi S, Roselli T, Rossano V. An Approach to Usability Evaluation of E-learning Applications. Universal Access in the Information Society 2006; 4(3): 270-83.

[13] Papert S, Resnick M. Technological Fluency and the Representation of Knowledge, Proposal to the National Science Foundation: MIT Media Laboratory 1993.

5.8 Appendix

A: Validation Guidelines and Instruments

Table A 1: *Instructional Guidelines*

Dear workshop/lesson leader,

please stick to the following instructions for validating your SCeTGo event.

Before the workshop:

1. Inform your SCeTGo contact person about the planned event (workshop/lesson, place, date, agenda, duration, number of participants, type of participants) via mail:
   Remark: Dear responsible SCeTGo partner, please fill in your email-address here!

2. Make sure that your SCeTGo contact person did provide the following files in your mother-language:
   Event information form
   Questionnaire
   Interview grid

3. Copy the questionnaire for all of your workshop participants. Copy the interview grid for at least 10 % of your workshop participants!

4. Schedule about 10-15 min for completing the questionnaire in your workshop and extra time for the interviews according to the number of interview partners (about 15 min per interview).

During the workshop:

1. Hand out the questionnaire to all participants immediately after the workshop.

2. Collect the questionnaire again after the participants completed it.

3. Ask at least 10 % of your participants to conduct a personal interview with you and make notes during the interview on the grid or use a dictaphone.

4. Complete the event information form so that we can structure the validation process.

After the workshop:

Send event information form, completed questionnaires and interview grid to the following address as soon as possible. Your contact person is responsible to coordinate the translation into English.
Remark: Dear SCeTGo partner, please fill in your address here!

Thank you!

Table A 2: *Event Information Form*

Event Information Form for Workshop/Lesson Leaders	
Dear workshop/lesson leader, please complete this information form after your workshop/lesson and send it together with the completed questionnaires and interview grids to your SCeTGo contact person: Dear SCeTGo partner, please list your address here!	
Name and profession of workshop/lesson leader(s)	
Location of workshop/lesson (e.g. Science center, Stockholm, Sweden)	
Duration of workshop/lesson	
Number and description of participants (in-service teachers, students, ...)	
Please briefly describe the agenda of the workshop/the topic of the lesson!	
How was the attitude of participants during the workshop/lesson?	
Which exhibits were part of the workshop/lesson?	
• MiniWing • Doppler Effect • Double-slit • Darwinism/Lamarck • Bolzmann • Double Cone • CERN • other(s): ______________________________	
Did something unexpected happen during the workshop? Any problems?	
Any further remarks?	

Table A 3: *Interview Grid for Teachers*

<table>
<tr><td colspan="3">SCeTGo Interview Grid – TEACHERS

Dear Interviewer,</td></tr>
<tr><td colspan="2">Please pick out 10 % of the attendees of your workshop for an individual interview.
The interview should
• be conducted individually,
• take place in a calm atmosphere
• and with no additional listeners.</td><td>Before the interview will start, please inform the attendee
• about the expected duration (15min) of the interview
• that his/her data are going to be treated anonymously.
• Ask him/her to tell you if he/she is not sure if he/she has understood something correctly.
Please take notes of the answers.</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Name of interviewer</td><td colspan="2"></td></tr>
<tr><td>Place</td><td colspan="2"></td></tr>
<tr><td>Date, time</td><td colspan="2"></td></tr>
<tr><td>Duration of interview</td><td colspan="2"></td></tr>
<tr><td>Gender of interviewed person</td><td colspan="2">☐ male ☐ female</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="2">0.a) What is your speciality - which subjects do you teach?</td><td>0.b) What level do you teach:
☐ primary
☐ inferior secondary/ gymnasium
☐ upper secondary/ highschool</td></tr>
<tr><td colspan="2">0.c) What is your citizenship?</td><td>0.c) How old are you?</td></tr>
<tr><td colspan="3">0.d) Please name the exhibits you have worked with today!</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td colspan="3">1. How did you take notice of the SCeTGo workshop?</td></tr>
<tr><td colspan="3">ANSWER:</td></tr>
<tr><td colspan="3">2. What have you expected from the SCeTGo workshop, concerning knowledge, attitudes, and values?</td></tr>
<tr><td colspan="3">ANSWER:</td></tr>
</table>

3. Did the SCeTGo workshop come up to your expectations, concerning knowledge, attitudes, and values?
ANSWER:
4. Are you motivated to take use of the SCeTGo approach in your future lessons? **If "no"**: Please mention the reasons, why you don't want to make use of the SCeTGo approach! **If "yes"**: What exactly convinced you, to make use of the SCeTGo approach?
ANSWER:
5. What do you think are the most positive aspects of the SCeTGo approach?
ANSWER:
6. Is there something you didn't understand, concerning the usage of the SCeTGo exhibits?
ANSWER:
7. Are you satisfied with the SCeTGo workshop? **If "no"**: What should be enhanced in future workshops? **If "yes"**: What did you like?
ANSWER:
8. Any further comments?
ANSWER:
Thank you for participating in the interview!

Table A 4: *Interview Grid for Students (school/university)*

<table>
<tr><td colspan="2">SCeTGo Interview Grid – STUDENTS
Dear Interviewer,</td></tr>
<tr><td>Please pick out 10 % of the attendees lesson for an individual interview.
The interview should
• be conducted individually,
• take place in a calm atmosphere
• and with no additional listeners.</td><td>Before the interview will start, please inform the attendee
• about the expected duration (15min) of the interview
• that his/her data are going to be treated anonymously.
• Ask him/her to tell you if he/she is not sure if he/she has understood something correctly.
Please take notes of the answers.</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Name of interviewer</td><td></td></tr>
<tr><td>Place</td><td></td></tr>
<tr><td>Date, time</td><td></td></tr>
<tr><td>Duration of interview</td><td></td></tr>
<tr><td>Gender of interviewed person</td><td>☐ male ☐ female</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>0.a) In which grade/semester are you?</td><td>0.b) What is your citizenship?</td></tr>
<tr><td colspan="2">0.c) How old are you?</td></tr>
<tr><td colspan="2">0.d) Please name the exhibits you have worked with today!</td></tr>
<tr><td colspan="2">0.e) Did you know in advance, that the lesson today would be a special self-guided one with computer-assissted miniature exhibits?</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2">1. Did you look forward to the lesson? Please, name the reasons.</td></tr>
<tr><td colspan="2">ANSWER:</td></tr>
</table>

2. What have you expected from the lesson?
ANSWER:
3. Did the lesson come up to your expectations?
ANSWER:
4. Did the lesson raise your interest in science? **If "no"**: Please mention the reasons, why you are not interested in science more than before the lesson! **If "yes"**: What exactly raised your interest?
ANSWER:
5. What do you think are the most positive aspects of this learning scenario, of this way of teaching?
ANSWER:
6. Is there something you didn't understand, concerning the usage of the computer-assisted miniature exhibits?
ANSWER:
7. Are you satisfied with the lesson? **If "no"**: What should be improved in future lessons? **If "yes"**: What did you like?
ANSWER:
8. Any further comments?
ANSWER:
Thank you for participating in the interview!

Table A 5: *Questionnaire for Teachers and Educators*

SCeTGo Workshop Validation

Questionnaire for Teachers

This questionnaire was created for the validation of SCeTGo workshops. To analyze the quality of the SCeTGo project and its activities all participants are asked to fill in this questionnaire carefully. Thank you!

First, we need some core data about you:

Your gender: ☐ male ☐ female

Your age: ___________ Your home country: ______________

Your role: ☐ School teacher; your subjects: ____________________

What level do you teach:

☐ primary

☐ inferior secondary/ gymnasium

☐ upper secondary/ highschool:

☐ University teacher; your discipline: ______________________

Please tick only one box per question!

Pedagogical validation	Low				High
How would you estimate ... ... the added value of the SCeTGo approach for your school?	☐	☐	☐	☐	☐
... the usability of the SCeTGo approach for your school?	☐	☐	☐	☐	☐
... the effectiveness of the SCeTGo approach for learning?	☐	☐	☐	☐	☐
... the integration of the SCeTGo approach in your current curriculum?	☐	☐	☐	☐	☐
How is your motivation for using the SCeTGo approach in teaching compared to how it was before the workshop?	☐	☐	☐	☐	☐

Technological validation	Low				High
How would you estimate… … the quality of the SCeTGo miniature exhibits?	☐	☐	☐	☐	☐
… the integration of the SCeTGo approach in your existing technological equipment (e.g. software compatibility, computer availability)?	☐	☐	☐	☐	☐
… the integration of the SCeTGo approach into management/organization procedures of your school?	☐	☐	☐	☐	☐
Economic validation					
Integration costs	Low				High
How would you predict the integration costs of the ICT-based SCeTGo approach into your school system?					
a) in terms of technological integration	☐	☐	☐	☐	☐
b) in terms of management integration	☐	☐	☐	☐	☐
c) in terms of teacher training and continous professional development?	☐	☐	☐	☐	☐
How would you predict in general the integration costs of ICT-based approaches into your school system?					
a) in terms of technological integration	☐	☐	☐	☐	☐
b) in terms of management integration	☐	☐	☐	☐	☐
c) in terms of teacher training and continous professional development?	☐	☐	☐	☐	☐
Cost (one miniature)	<50	50-100	100-150	150-200	more:
How much € would you be ready to pay to use the miniatures in your class (tentative)	☐	☐	☐	☐	☐
Cost (set of 5 miniatures)	<100	100-500	500-1000	1000-1500	more:
How much € would you be ready to pay to use the whole set of miniatures in your class (tentative)	☐	☐	☐	☐	☐

Potential value/usefulness	strongly disagree				strongly agree
I believe this activity could be of some value to students.	☐	☐	☐	☐	☐
I think that doing this activity is useful for students.	☐	☐	☐	☐	☐
I think this activity is important to do for students.	☐	☐	☐	☐	☐
I would be willing to do this more than once with my students because it has some value to them.	☐	☐	☐	☐	☐
I think doing this activity could help students.	☐	☐	☐	☐	☐
I believe doing this activity could be beneficial to students.	☐	☐	☐	☐	☐
I think this is an important activity for students.	☐	☐	☐	☐	☐
Intrinsic motivation	**strongly disagree**				**strongly agree**
I enjoyed doing this activity very much.	☐	☐	☐	☐	☐
This activity was fun to do.	☐	☐	☐	☐	☐
I thought this was a boring activity.	☐	☐	☐	☐	☐
This activity did not hold my attention at all.	☐	☐	☐	☐	☐
I would describe this activity as very interesting.	☐	☐	☐	☐	☐
I thought this activity was quite enjoyable.	☐	☐	☐	☐	☐
While I was doing this activity, I was thinking about how much I enjoyed it.	☐	☐	☐	☐	☐

Table A 6: *Questionnaire for Students (School/University)*

<table>
<tr><td colspan="6">SCeTGo Lesson Validation

Questionnaire for Students

This questionnaire was created for the validation of SCeTGo lessons. To analyze the quality of the SCeTGo project and its activities all participants are asked to fill in this questionnaire carefully. Thank you!</td></tr>
<tr><td colspan="6">First, we need some core data about you:

Your gender: ☐ male ☐ female

Your age: ___________ Your grade/semester: _____________ Your home country: ______________</td></tr>
<tr><td colspan="6">Your role: ☐ School student; favourite subjects: _________________________

☐ University student; your subject(s): __________________________

☐ Other; Reason for visit: _____________________________________</td></tr>
<tr><td>Please tick only one box per question!</td><td>Low</td><td></td><td></td><td></td><td>High</td></tr>
<tr><td>Do you think your way of learning could change with the use of such learning scenarios as today that are self-guided and use computer-assisted exhibits?</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td>How is your engagement in such learning scenarios compared to how it was before this lesson?</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td>How would you estimate the use of such learning scenarios (self-guided, use of computer-assisted exhibits) in the process of innovation in learning?</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td>How would you estimate the integration of such learning scenarios for fulfilling your personal needs of learning?</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td>How would you estimate the effectiveness of such learning scenarios (that are self-guided and use computer-assisted exhibits) for your learning process?</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td>How is your motivation for learning with the use of such learning scenarios compared to how it was before the lesson?</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
<tr><td>How is the quality of the computer-assissted miniature exhibits that have been provided to you during this lesson?</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr>
</table>

Please tick only one box per question!	strongly disagree				strongly agree
I tried hard to do well in these activities.	☐	☐	☐	☐	☐
I think I was pretty good at these activities.	☐	☐	☐	☐	☐
I enjoyed learning these things during this lesson.	☐	☐	☐	☐	☐
What I learned during this lesson is relevant to my life.	☐	☐	☐	☐	☐
In this lesson, I worked as hard as I could.	☐	☐	☐	☐	☐
These activities were fun.	☐	☐	☐	☐	☐
After working at these activities for a while, I felt pretty competent.	☐	☐	☐	☐	☐
Understanding these tasks gave me a sense of accomplishment.	☐	☐	☐	☐	☐
I will use more strategies that ensure I learn the science well, than I did before this lesson.	☐	☐	☐	☐	☐
When we worked on these tasks, I felt interested.	☐	☐	☐	☐	☐
During these activities, I participated in task-related discussions.	☐	☐	☐	☐	☐
I liked the tasks that challenged me.	☐	☐	☐	☐	☐
I am satisfied with my performance at these tasks.	☐	☐	☐	☐	☐
What I learned during this lesson has practical value for me.	☐	☐	☐	☐	☐
What I learned during this lesson is more important to me than the grade I might have received.	☐	☐	☐	☐	☐
I will prepare better for the science tests and labs than I did before this lesson.	☐	☐	☐	☐	☐
I paid attention during these activities.	☐	☐	☐	☐	☐
I think about how I will use what I learned during this lesson.	☐	☐	☐	☐	☐
These were activities that I couldn't do very well.	☐	☐	☐	☐	☐
If I am having trouble learning the science, I will try to figure out why more intenseley than before this lesson.	☐	☐	☐	☐	☐

When we worked on these activities, I got involved.	☐	☐	☐	☐	☐
I was pretty skilled at these activities.	☐	☐	☐	☐	☐
I enjoyed learning these things.	☐	☐	☐	☐	☐
I think about how the things I learned during this lesson will be helpful to me.	☐	☐	☐	☐	☐
During the lesson, I listened very carefully.	☐	☐	☐	☐	☐
I will put more effort into learning the science than I did before this lesson.	☐	☐	☐	☐	☐
I think I did pretty well at this activity, compared to other students.	☐	☐	☐	☐	☐
What I learned during this lesson relates to my personal goals.	☐	☐	☐	☐	☐
When doing these activities, I felt good.	☐	☐	☐	☐	☐
I found learning these things interesting.	☐	☐	☐	☐	☐

Table A 7: *Intrinsic Motivation, Science Motivation, and Student Engagement items (sorted)*

Perceived competence	**Personal relevance**
I think I was pretty good at these activities.	I found learning these things interesting.
I think I did pretty well at this activity, compared to other students.	I enjoyed learning these things.
After working at these activities for a while, I felt pretty competent.	What I learned during this lesson has practical value for me.
I am satisfied with my performance at these tasks.	What I learned during this lesson is relevant to my life.
I was pretty skilled at these activities.	What I learned during this lesson is more important to me than the grade I might have received.
These were activities that I couldn't do very well.	What I learned during this lesson relates to my personal goals.
Behavioral engagement	I liked the tasks that challenged me.
I tried hard to do well in these activities.	Understanding these tasks gave me a sense of accomplishment.
In this lesson, I worked as hard as I could.	I think about how I will use what I learned during this lesson.
During these activities, I participated in task-related discussions.	I think about how the things I learned during this lesson will be helpful to me.
I paid attention during these activities.	
During the lesson, I listened very carefully.	
Emotional engagement	**Self-determination**
When doing these activities, I felt good.	I will put more effort into learning the science than I did before this lesson.
When we worked on these tasks, I felt interested.	I will prepare better for the science tests and labs than I did before this lesson.
These activities were fun.	I will use more strategies that ensure I learn the science well, than I did before this lesson.
I enjoyed learning these things during this lesson.	If I am having trouble learning the science, I will try to figure out why more intenseley than before this lesson.
When we worked on these activities, I got involved.	

5.9 Appendix (Results)

5.9.1 Phase A; Quantitative Research

Survey of Students (school)

Mini-Wing (Wing Dynamics)

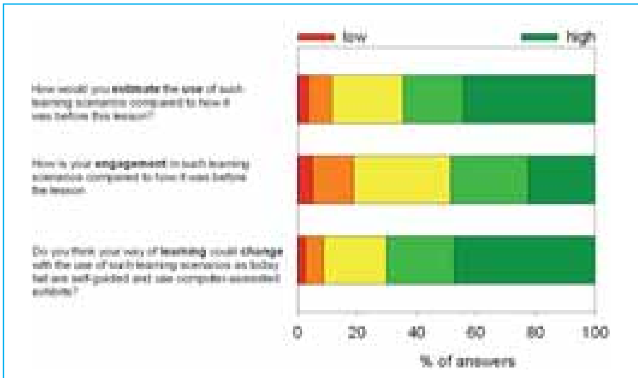


Fig. 5.33: Evaluation of Pedagogical Aspects I (VALNet)

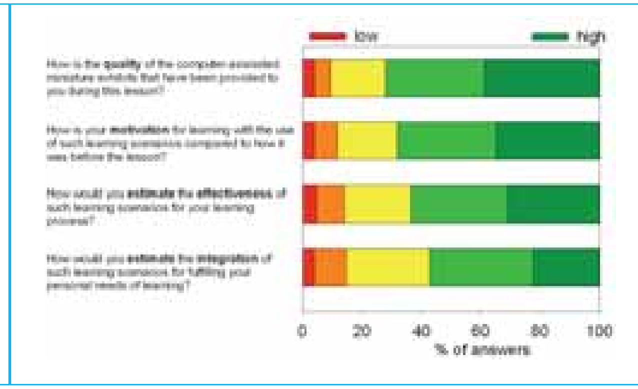


Fig. 5.34: Evaluation of Pedagogical Aspects II (VALNet)

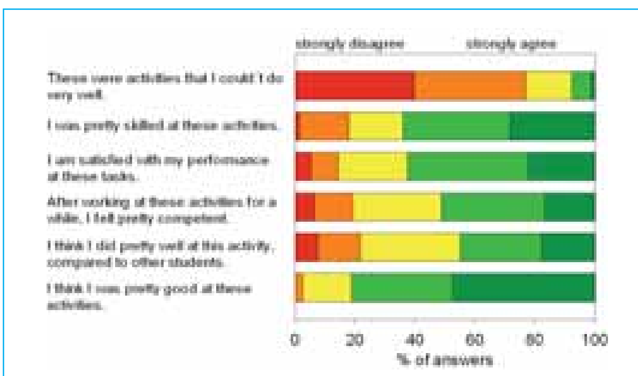


Fig. 5.35: Evaluation of Perceived Competence (Intrinsic Motivation Inventory)

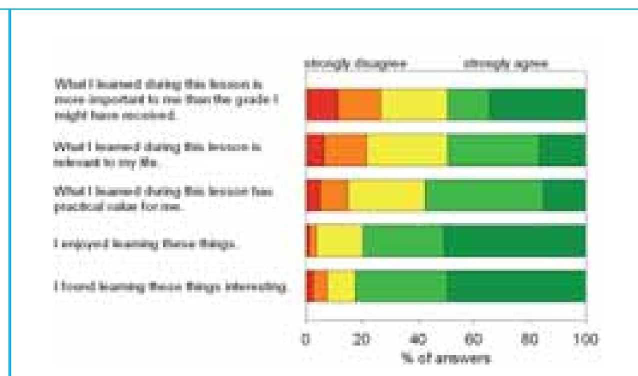


Fig.5.36: Evaluation of Personal Relevance I (Science Motivation Questionnaire)

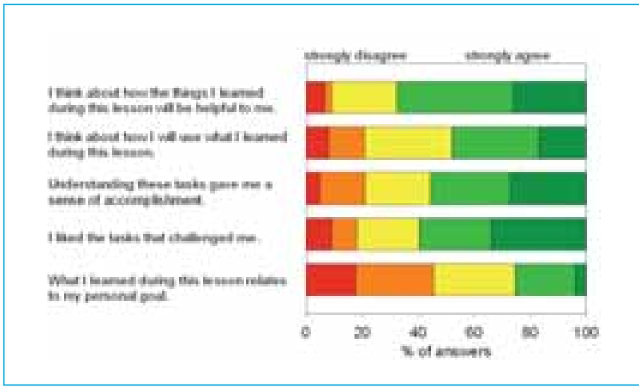


Fig. 5.37: *Evaluation of Personal Relevance II (Science Motivation Questionnaire)*

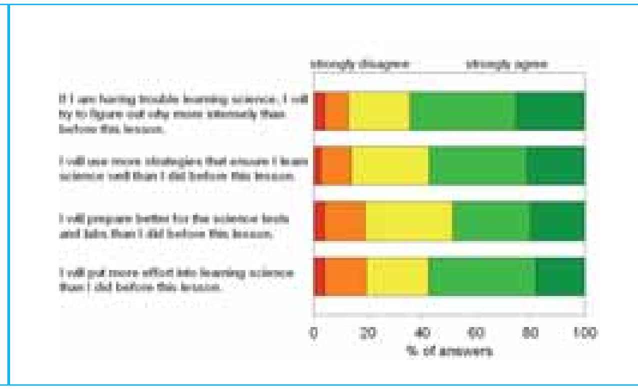


Fig. 5.38: *Evaluation of Self-determination (Science Motivation Questionnaire)*

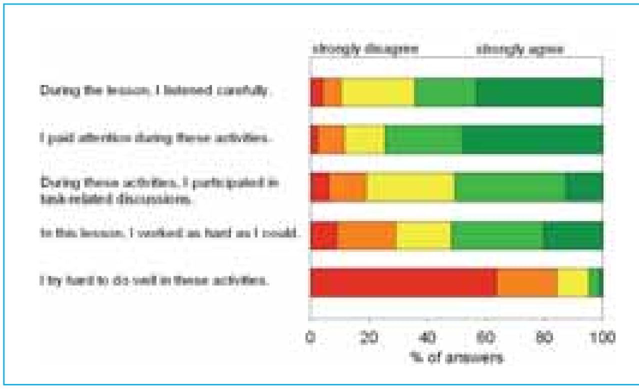


Fig.5.39: *Evaluation of Behavioral Engagement (Student Engagement Questionnaire)*

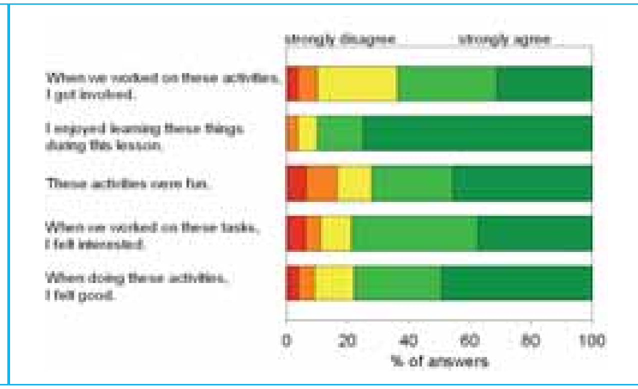


Fig.5.40: *Evaluation of Emotional Engagement (Student Engagement Questionnaire)*

Mini-Firetruck (Doppler Effect)

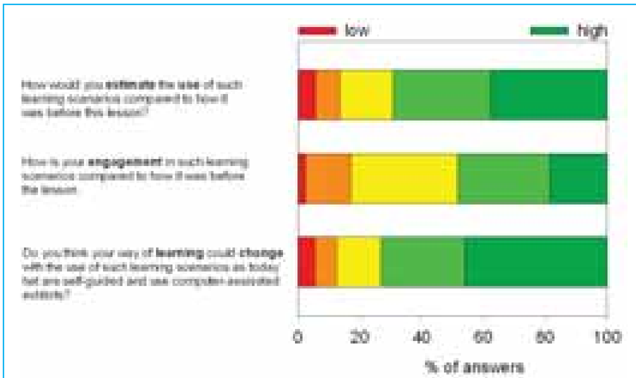


Fig. 5.41: *Evaluation of Pedagogical Aspects I (VALNet)*

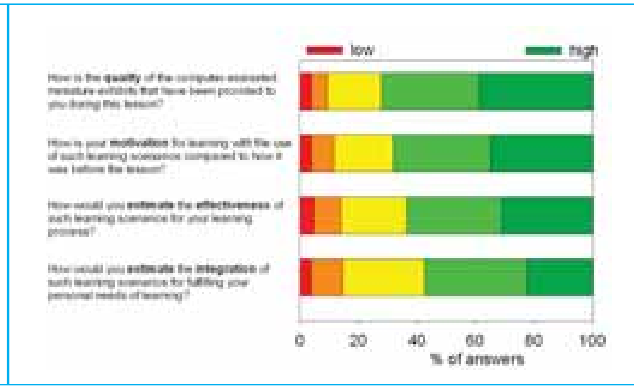


Fig. 5.42: *Evaluation of Pedagogical Aspects II (VALNet)*

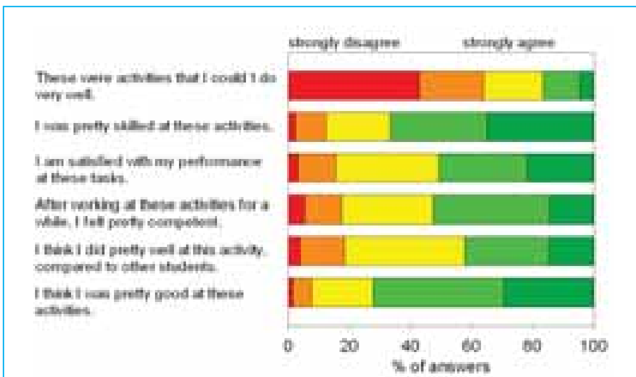


Fig. 5.43: *Evaluation of Perceived Competence (Intrinsic Motivation Inventory)*

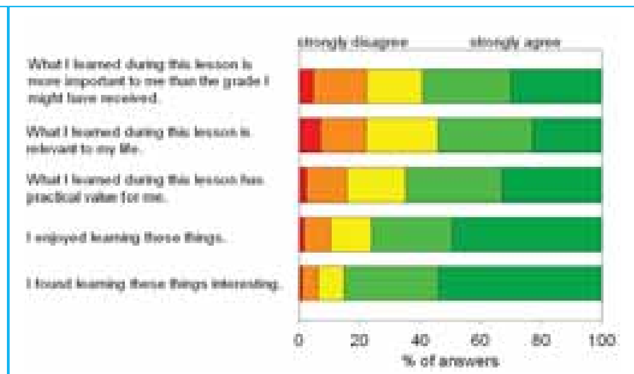


Fig. 5.44: *Evaluation of Personal Relevance I (Science Motivation Questionnaire)*

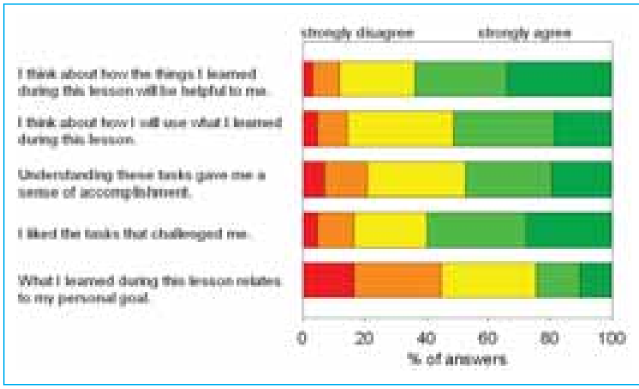


Fig. 5.45: Evaluation of Personal Relevance II (Science Motivation Questionnaire)

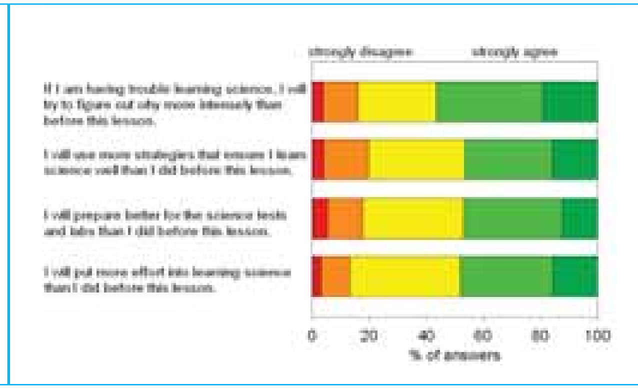


Fig. 5.46: Evaluation of Self-determination (Science Motivation Questionnaire)

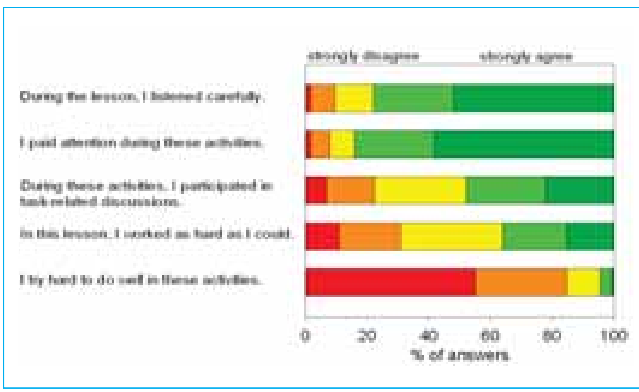


Fig. 5.47: Evaluation of Behavioral Engagement (Student Engagement Questionnaire)

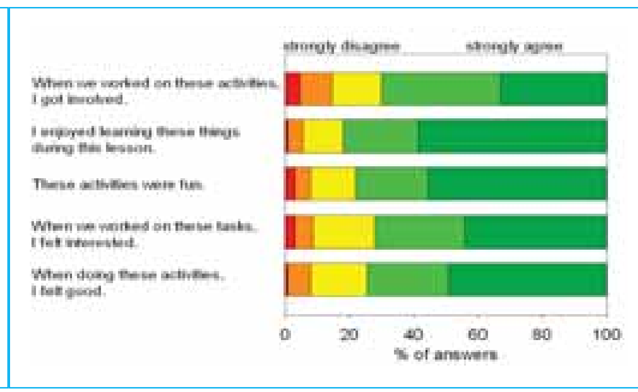


Fig. 5.48: Evaluation of Emotional Engagement (Student Engagement Questionnaire)

Mini-Double Cone (Classical Mechanics)

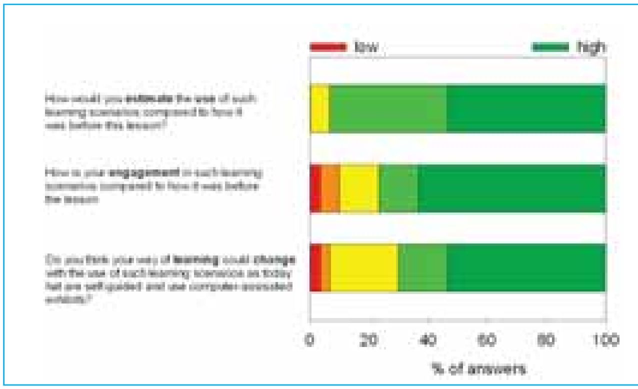


Fig. 5.49: *Evaluation of Pedagogical Aspects I (VALNet)*

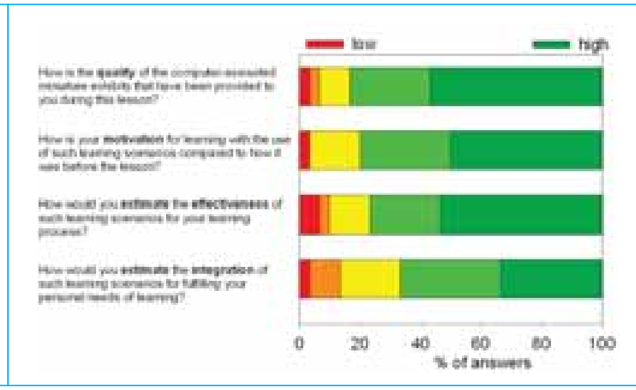


Fig. 5.50: *Evaluation of Pedagogical Aspects II (VALNet)*

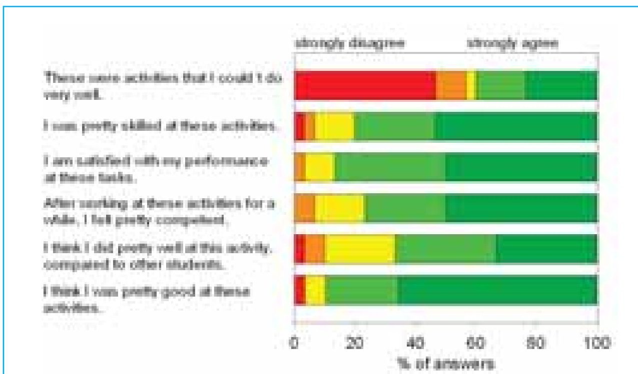


Fig. 5.51: *Evaluation of Perceived Competence (Intrinsic Motivation Inventory)*

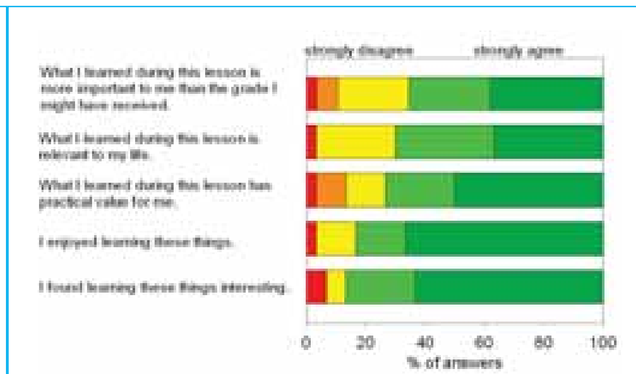


Fig. 5.52: *Evaluation of Personal Relevance I (Science Motivation Questionnaire)*

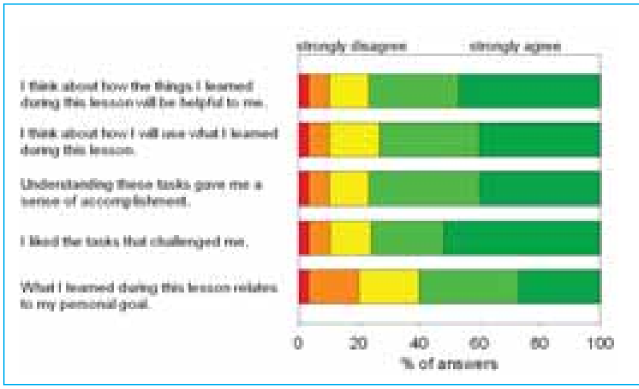


Fig. 5.53: Evaluation of Personal Relevance II (Science Motivation Questionnaire)

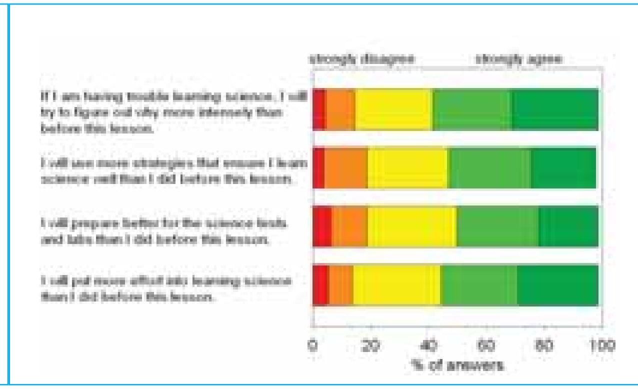


Fig. 5.54: Evaluation of Self-determination (Science Motivation Questionnaire)

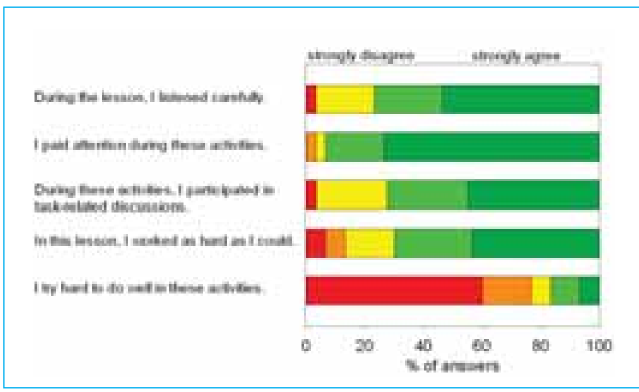


Fig. 5.55: Evaluation of Behavioral Engagement (Student Engagement Questionnaire)

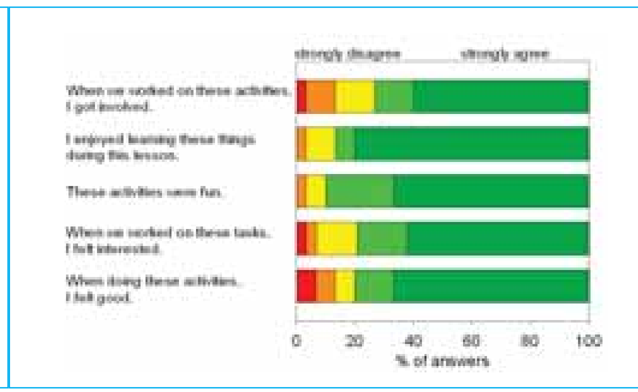


Fig. 5.56: Evaluation of Emotional Engagement (Student Engagement Questionnaire)

Mini-Double Slit (Quantum Mechanics)

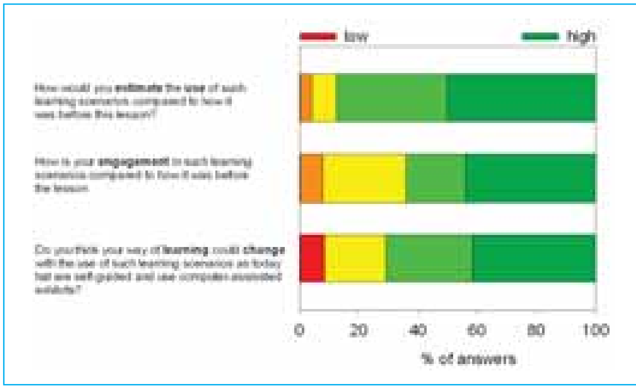


Fig. 5.57: *Evaluation of Pedagogical Aspects I (VALNet)*

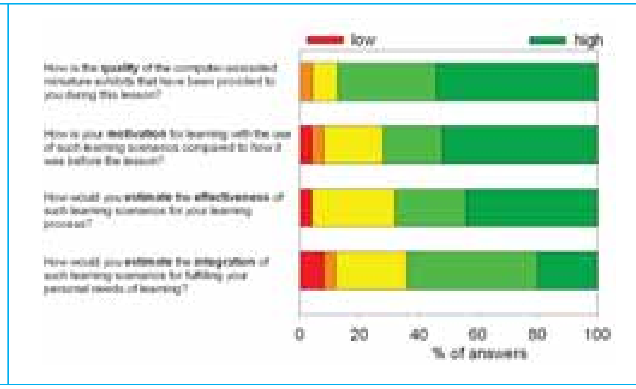


Fig. 5.58: *Evaluation of Pedagogical Aspects II (VALNet)*

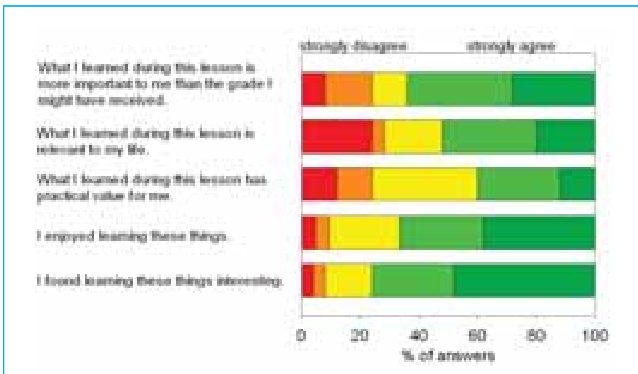


Fig. 5.59: *Evaluation of Personal Relevance I (Science Motivation Questionnaire)*

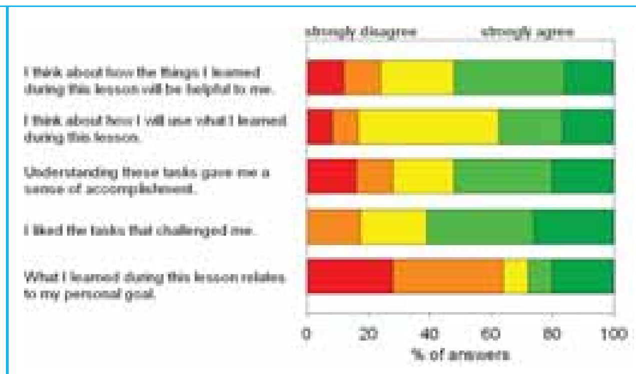


Fig. 5.60: *Evaluation of Personal Relevance II (Science Motivation Questionnaire)*

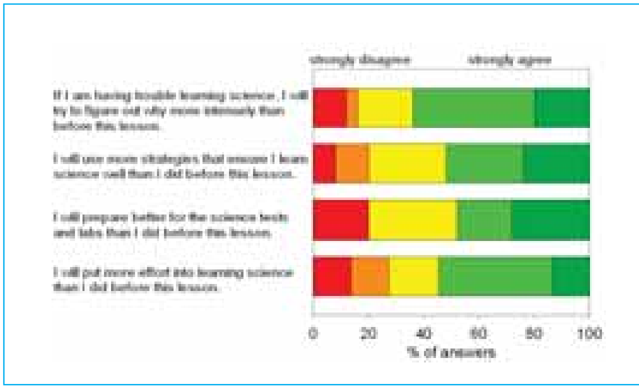


Fig. 5.61: *Evaluation of Self-determination (Science Motivation Questionnaire)*

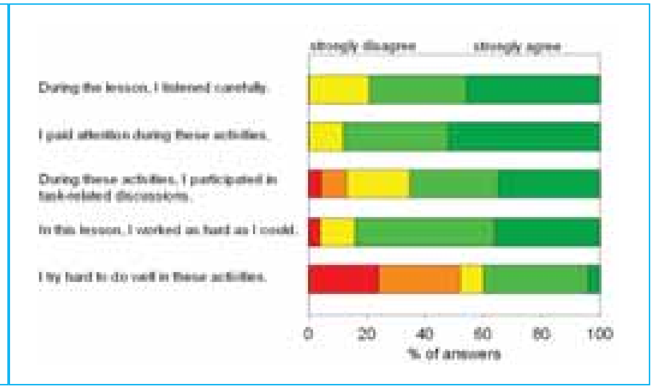


Fig. 5.62: *Evaluation of Behavioral Engagement (Student Engagement Questionnaire)*

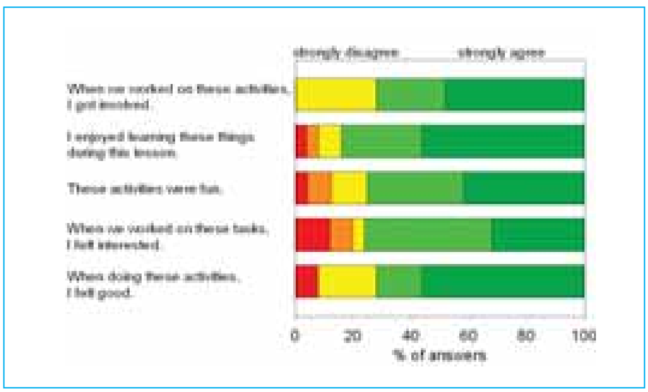


Fig. 5.63: *Evaluation of Emotional Engagement (Student Engagement Questionnaire)*

5.92 Phase B

Survey of Students (university)

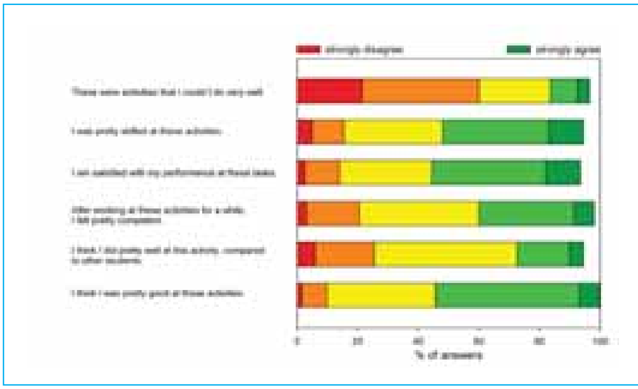


***Fig. 5.64:** Evaluation of Perceived Competence (Intrinsic Motivation Inventory)*

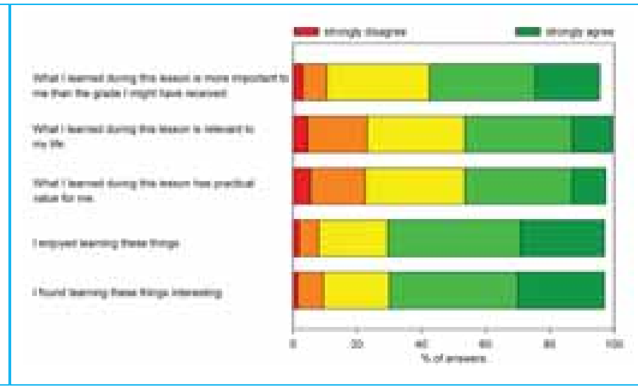


***Fig. 5.65:** Evaluation of Personal Relevance I (Science Motivation Questionnaire)*

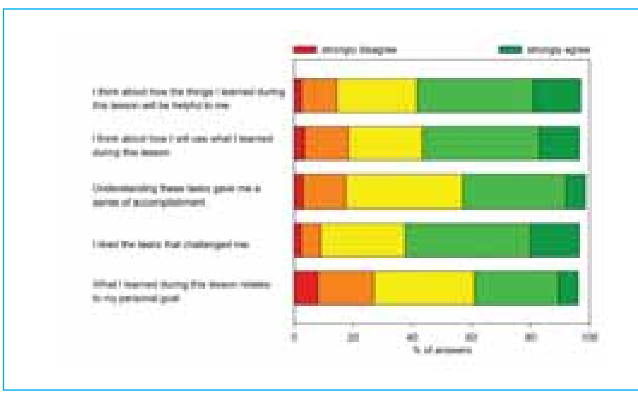


***Fig.5.66:** Evaluation of Personal Relevance II (Science Motivation Questionnaire)*

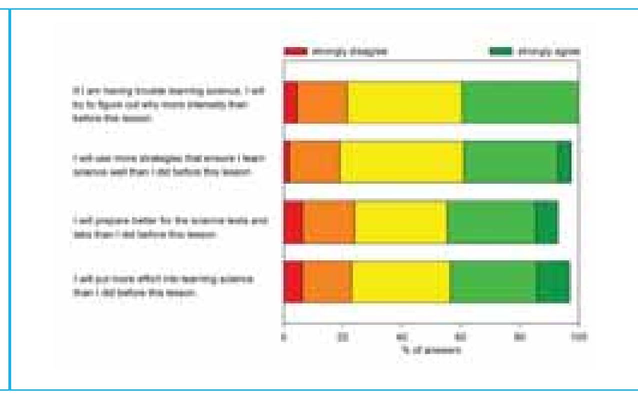


***Fig. 5.67:** Evaluation of Self-determination (Science Motivation Questionnaire)*

Survey of Students (school)

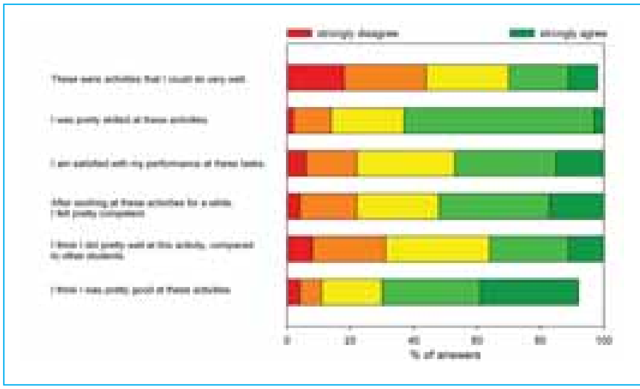


Fig. 5.68: Evaluation of Perceived Competence (Intrinsic Motivation Inventory)

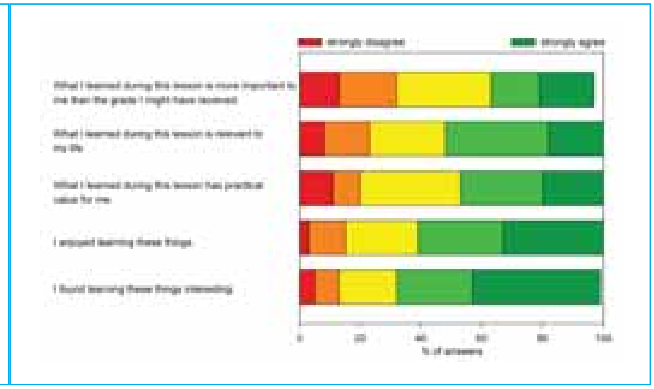


Fig. 5.69tionnaire)

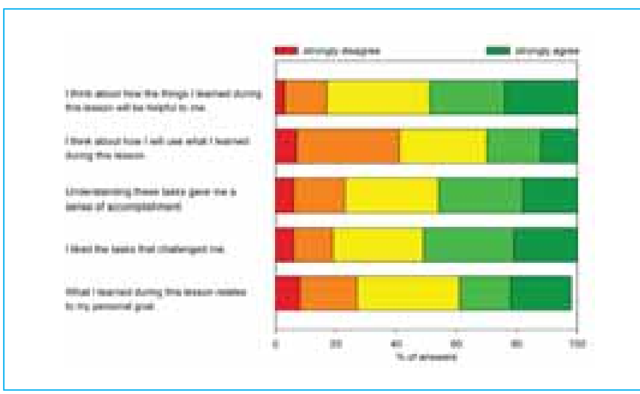


Fig. 5.70: Evaluation of Personal Relevance II (Science Motivation Questionnaire)

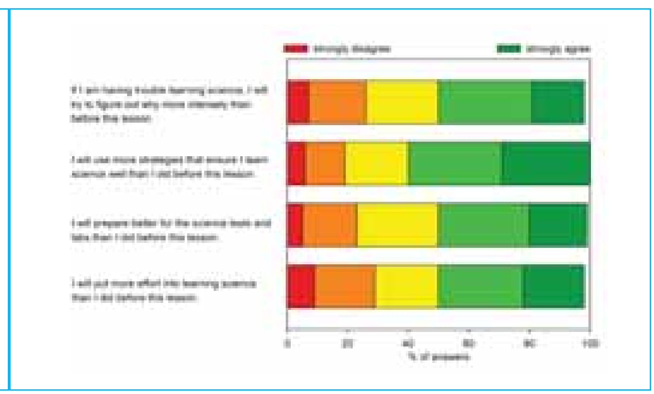
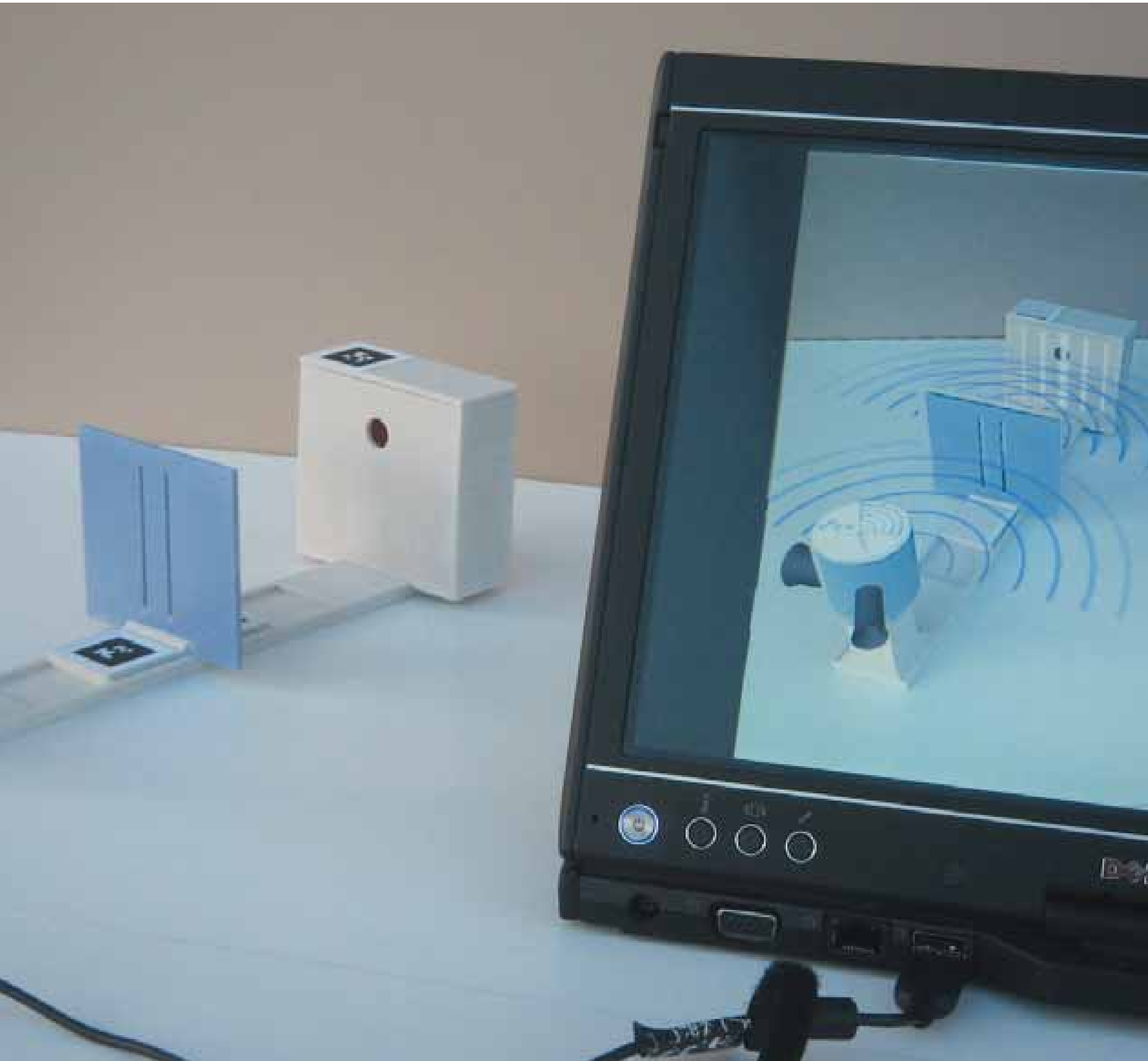


Fig. 5.71: Evaluation of Self-determination (Science Motivation Questionnaire)

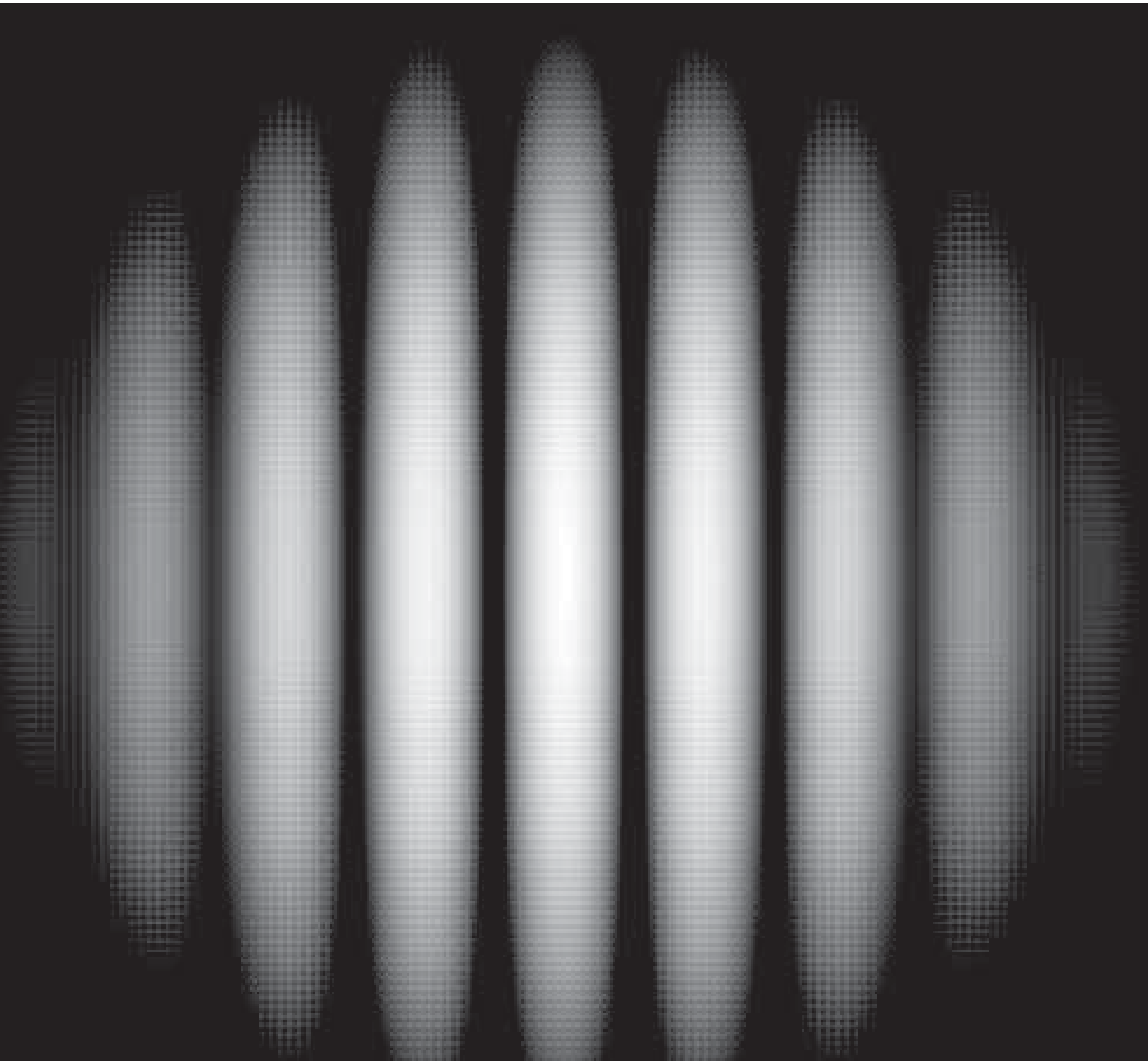


6. A SCeTGo Special Case

Assessing the impact of the Science Center to Go system on the understanding of quantum interpretation of the Double Slit Experiment

Light and matter are both single entities, and the apparent duality arises in the limitations of our language.

Heisenberg



6.1 Introduction and Background

Introductory courses in classical physics as well as everyday experience generally promote in students a realist perspective that is both deterministic and local. From this classical point of view, physical quantities such as the position and momentum of a particle have an objective existence independent of experimental observation, and measurements performed on one system cannot affect the outcome of measurements performed on another system that is physically isolated from the first. Such assumptions can be justified when dealing with the macroscopic world, and teaching classical physics in this way has the advantage of appealing to students' everyday intuitions. However, many introductory modern physics students consequently face significant hurdles when they first learn about the decidedly probabilistic and nonlocal theory of quantum mechanics, which precludes any local realist interpretation.

In terms of assessing student difficulties in quantum mechanics, several conceptual surveys have been developed, though most are appropriate for advanced undergraduate and beginning graduate students since they address topics such as the calculation of expectation values, or the time evolution of quantum states. The Quantum Physics Conceptual Survey [1] is the most recently developed assessment instrument designed specifically for introductory modern physics students. The authors of the QPCS found that modern physics students had the most difficulty with six questions which they classified as interpretive; for example, the two survey items with the lowest percentage of correct responses ask whether, "according to the standard Copenhagen interpretation of quantum mechanics," Light or an electron is behaving like a wave or a particle when traveling from a source to a detector. The authors report that only 20% of students chose the correct response for each of these two questions. As the authors note, this parallels a finding by Mazur [2] when comparing student performance on conventional physics problems versus ones requiring conceptual understanding. These results suggest that many introductory modern physics students may grasp how to use the computational tools of quantum mechanics, without a corresponding facility with notions such as wave-particle duality that are at odds with their classical intuitions.

In their paper Baily & Finkelstein [3] discussing the impact of the instruction on students understanding of quantum phenomena focusing on the interpretation of the double slit experiment. According to their study Another modern physics instructors found that quantum interpretations were particularly useful in constructing models during their many years of teaching, and they were explicit in teaching such a model to their students when discussing the double-slit experiment by telling them that each electron must pass through both slits simultaneously and interfere with itself on its way from the source to the detector. When asked at the end of the semester about their preferred interpretation of the double-slit experiment, students from a modern physics course where the instructor was explicit in teaching a quantum interpretation overwhelmingly chose to agree with a statement that describes each electron as a delocalized wave packet that propagates through both slits. However, a significant majority of students from a second modern physics course, taught by an instructor that was not focusing on the quantum interpretation said they preferred a realist interpretation, agreeing that each electron is a tiny particle that travels through one slit or the other on its way to the detector. Almost every student who had said they preferred a realist interpretation of the double-slit experiment also agreed that an electron in an atom must have a definite position at all times, which would again be consistent with a realist perspective; nearly half of the students who had preferred the wave-packet description of an electron in the double-slit experiment also agreed with this realist statement about atomic electrons. Among the conclusions drawn from these results were:

1) instructors can have a significant impact on student perspectives in contexts where they are explicit about teaching interpretations of quantum processes; and

2) students seem more likely to default to realist interpretations of quantum phenomena when instructors are not explicit in promoting an alternative perspective.

6.2 Tools and Methodology

Our aim with this note is to set a framework for assessing the impact of the Science Center to Go Augmentations to the instruction of the Double Slit Experiment. Our methodology includes the implementation of the six QPCS questions (6.7 Appendix) which are classified as interpretive and interviews with students focusing on the comparison of the behavior of the atomic electrons and the electrons at the Double Slit Experiment.

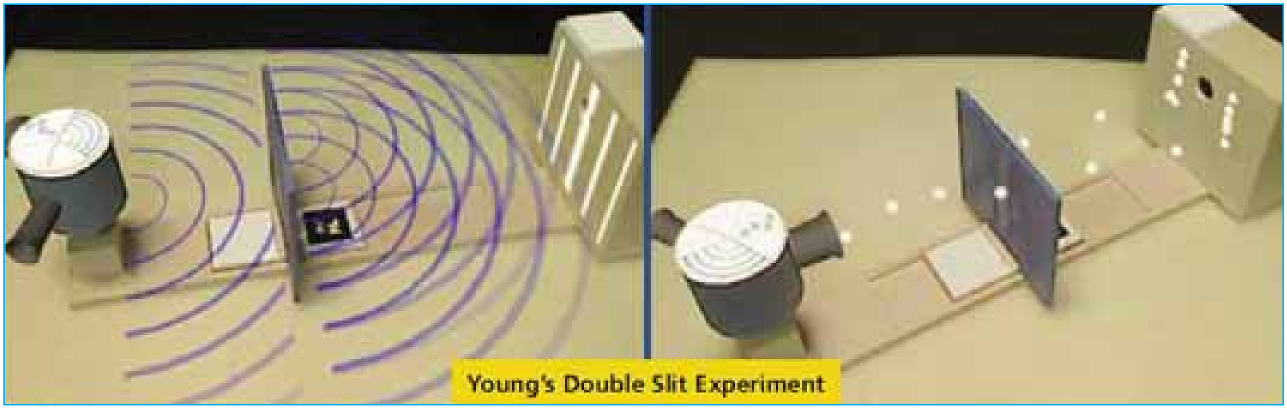


Figure 6.1: *The Science Center to Go Augmentations for the Double Slit Experiment.*

The double-slit experiment is a natural sub-topic in the discussion of photons, since it requires both a wave and a particle description of quanta in order to completely account for experimental observations. In this experiment, a mono chromatic beam impinges on two closely spaced slits and diffracts; wavelets spread out behind the slits and interfere in the regions where they overlap, with bright fringes appearing on the detection screen where the antinodal lines intersect.

The wave description of quanta explains the interference pattern on the detection screen, while a particle description addresses the fact that individual quanta are detected as localized particles. In our case the Science Center to Go system was used to present the phenomenon to the students (Figure 6.1). Additionally the Colorando Quantum Wave Interference simulation [4] was presented in class to provide students with a visualization of the process of the electrons interference and especially to simulate the passage of the electron from the slits (see Figure 6.2).

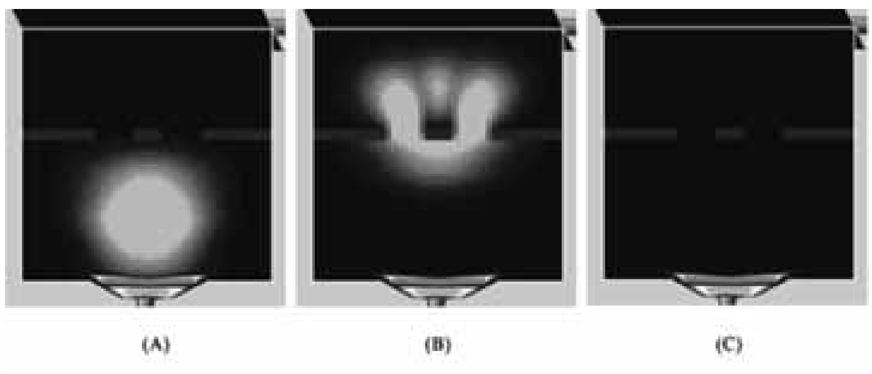


Figure 6.2: *A sequence of screenshots from the Quantum Wave Interference simulation.*

6.3 Analysis and Results (February 2011)

Here we present an initial analysis of the data that were collected in the framework of a series of lessons realized in Ellinogermaniki Agogi (EA) School in February 2011. 54 students participated (age 17-18 years old). 24 of them were interviewed in order to perform a more in depth analysis of the initial findings. The results from the implementation of the six items questionnaire (following the instruction and the demonstration) are shown in Figure 6.3, where responses were categorized simply by which fictional student(s) the respondents agreed with (Quantum, Realist, or Agnostic), whatever their reasoning might be. While most students chose to agree with only a single statement, there were a few respondents who chose to agree with both the fictional Realist and Agnostic students, or with both the Quantum and the Agnostic students; we felt the Realist and Quantum statements were not incompatible with the Agnostic statement, since agreeing with the latter allowed students to acknowledge that they had no way of actually knowing if their preferred interpretations were correct. The relatively few students who responded in this way were grouped together with the other students in the Realist or Quantum categories, as appropriate.

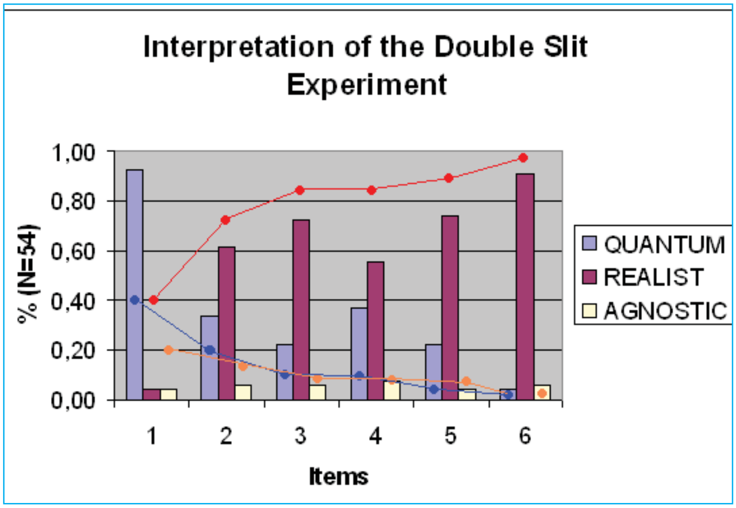


Figure 6.3: The results from the application of the six items questionnaire are presented in comparison with the average values of the QPCS. At the first four questions the impact of the Science Center to Go system is obvious. In questions 5 and 6 which are quite complex and difficult the Realist explanations are dominant.

Here is an example of the different students' interpretations:

Student One (Realist): The probability density is so large because we don't know the true position of the electron. Since only a single dot at a time appears on the detecting screen, the electron must have been a tiny particle, traveling somewhere inside that blob, so that the electron went through one slit or the other on its way to the point where it was detected.

Student Two (Quantum): The blob represents the electron itself, since an electron is described by a wave packet that will spread out over time. The electron acts as a wave and will go through both slits and interfere with itself. That's why a distinct interference pattern will show up on the screen after shooting many electrons.

Furthermore as the physics textbook presents the electron in the Schrodinger atomic model as "a cloud of probability surrounding the nucleus whose wave function is the solution of the Schrodinger equation," without further elaboration with respect to interpretation we were interested in knowing if how students came to think of quanta in the context of the double-slit experiment would be relevant to how they perceived an electron in an atom, particularly when they had not been given the same kind of explicit instruction in this topic area as with the double-slit experiment. So in addition to the essay questions, a post instruction guided interview asked students to respond to the following statement using a five-point scale ranging from strong disagreement to strong agreement: "An electron in an atom has a definite but unknown position at each moment of time." Students were also asked to provide the reasoning behind their responses in a textbox following the statement. Disagreement with the statement would be consistent with both a quantum or agnostic perspective, whereas agreement with the statement would be more consistent with a realist perspective. 13 students who have answered questions 1 to 4 following the quantum interpretation were intervened. Additionally 11 students who have demonstrated a clear realist perspective especially in questions 2 to 4 were also interviewed. The results are presented in Figure 6.4.

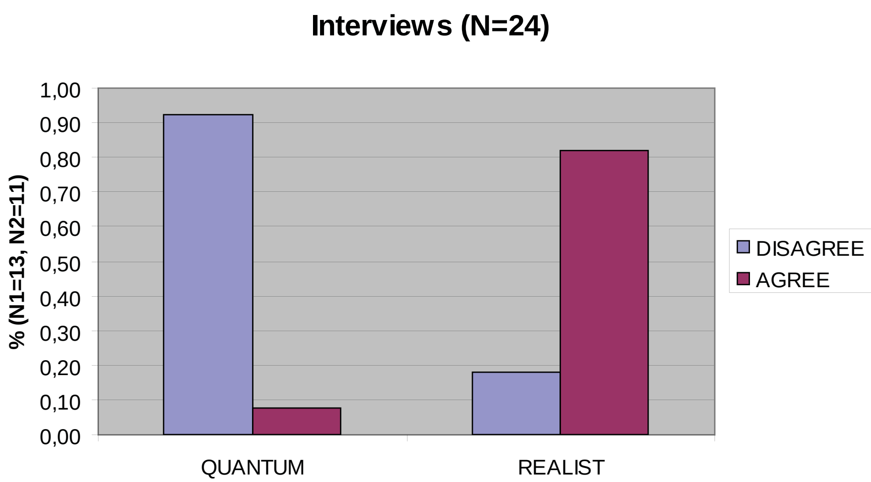


Figure 6.4: *Almost all students who have answered the questionnaire following a quantum perspective disagree with the statement that the electron has a defined position in an atom.*

The results from the interviews are very important taking into account that previous studies [3] only half of the students are capable to interconnect the behavior of atomic electrons and the electrons in the double slit experiment. Usually the majority of students favor a realist perspective in the case of the atom. The results in the case of our study demonstrate that the SCeTGo system could help instructors to perform the necessary interpretations that could help students to understand more effectively quite complex phenomena.

6.4 Conclusions

Our study indicates that the Science Center to Go system could help students to understand quite complex phenomena taking into account that the teachers should be aware of the potential impact they may have on student thinking as a consequence of their instructional choices regarding interpretation. Students do not come into a course on modern physics as “blank slates” with regard to interpretive ideas, and that instructors who spend less time explicitly attending to student prior knowledge and intuition are less likely to transition students to consistent perspectives that are not realist. As the three courses realized at EA School, student perspectives seem to be highly context dependent. Many students have demonstrated mixed perspectives that may seem contradictory to expert physicists, indicating the need for a more detailed exploration of student perspectives in quantum physics beyond the broad characterizations of Realist, Quantum, or Agnostic, which is the subject of current studies.

6.5 Notes

The above study, that has been performed by Elpida Giallouri (National Technical University of Athens), Angelos Lazoudis & Sofoklis Sotiriou (Ellinogermaniki Agogi) and was initially presented during the EDEN Open Classroom Conference [4], is part of a larger study taking place in Greece. This study aims to assess the impact of the Science Center To Go System on the understanding of quantum interpretation of the Double Slit Experiment not only by high school students (age 17-19) but also by undergraduates as well. The findings of this study are expected to be published in a peer review journal before the summer of 2013.

A full description of the “SCeTGo Double Slit Scenario” can be found in Chapter 4. Moreover, a detailed worksheet that serves in supporting the students in writing down their observations and outcomes is shown in 6.7 Appendix A. Finally, 6.7 Appendix B and C include the conceptual understanding test and a semi-structured interview template that were used data collection tools for the assessment of the implemented scenario.

6.6 References

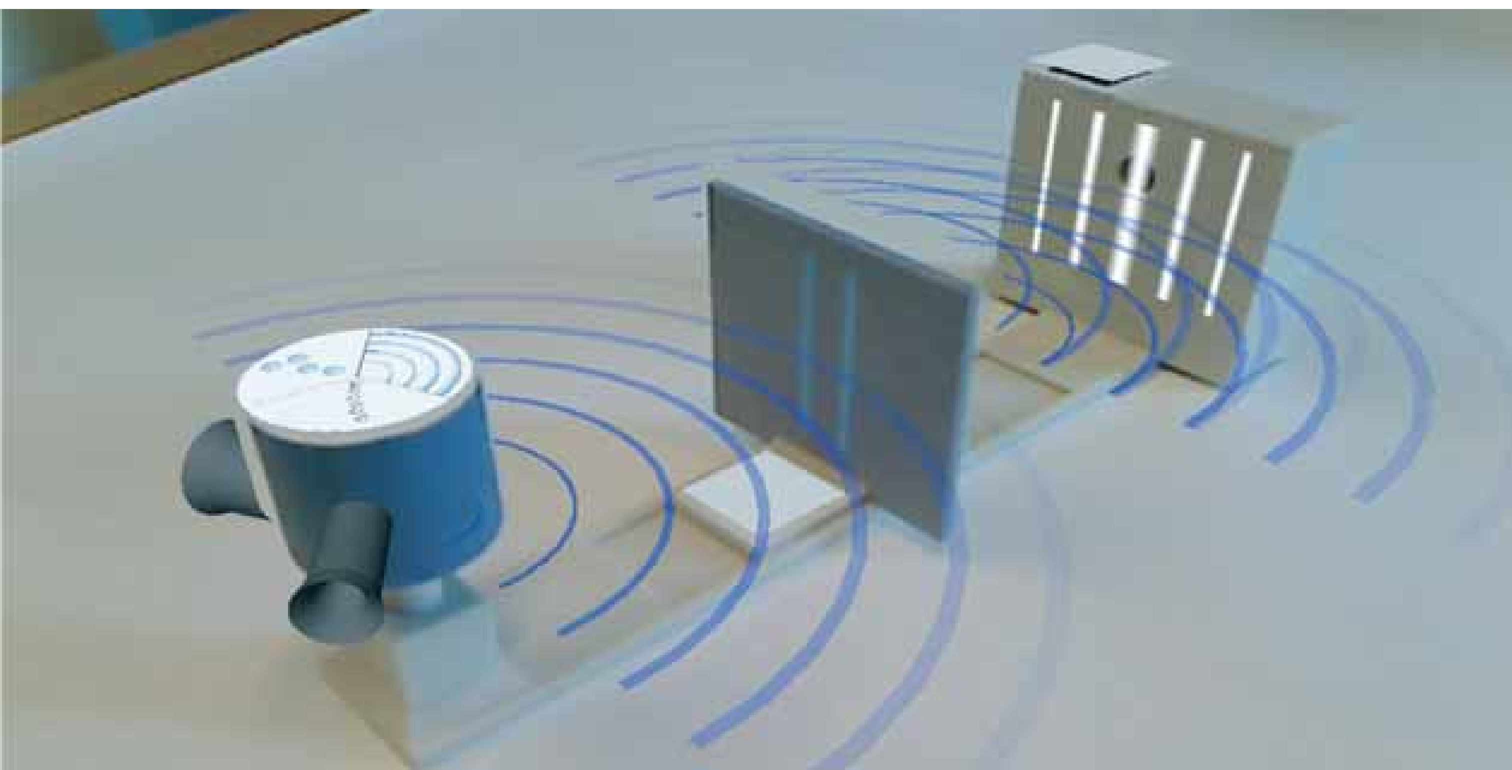
[1] S. Wuttiprom, M. D. Sharma, I. D. Johnston, R. Chitaree, and C. Soankwan, Development and Use of a Conceptual Survey in Introductory Quantum Physics, Int. J. Sci. Educ. 31, 631 2009.

[2] E. Mazur, Peer Instruction: A User's Manual Prentice Hall, New York, NY, 1997

[3] Baily C., and Finkelstein N.D., Teaching and understanding of quantum interpretations in modern physics courses Phys. Rev. St Phys. Educ. Res. 6, DOI 010101 (2010)

[4] http://phet.colorado.edu/el/simulation/quantum-wave-interference

[5] Giallouri E., Lazoudis A., Sotiriou S., "Assessing the impact of the Science Center to Go System on the understanding of quantum interpretation of the Double-slit Experiment", Augmented Reality in Education: Proceedings of the EDEN Open Classroom Conference 2011, Athens, Greece, October 27-29, 2011. ISBN: 978-960-473-328-6



6.7 Appendix A STUDENT WORKSHEET

Science Center To Go

A mixed reality learning environment of miniature exhibits

Place the one slit frame and observe in the computer the image created on the screen by the light beam.

Place the two slits frame and observe in the computer the image created on the screen by the light beam again

Place the one slit frame and observe in the computer the image created on the screen by the canon beam

Place the two slits frame and observe in the computer the image created on the screen by the canon beam again

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Based on how waves interfere and by what you see on the screen, explain how electrons travel through the double slit and on to the screen.

Can you predict where exactly the next electron will appear on the screen?

Based on the image on the screen, do you see a wave-like behavior of electrons?

Write down any other comments you want based on your observations.

6.7 Appendix B CONCEPTUAL UNDERSTANDING TEST

Science Center To Go

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Dear Teacher,

This is the **Assessment Test** for **the Double Slit Miniature Exhibit**. This Test has to be delivered to the students following the realization of the experiment. The process for implementing the proposed activities in the classroom are described in detail in the Science Center To Go Double Slit Pathway.

Dear Student,

The Science Center To Go Double Slit experiment simulates one of the most interesting experiments in physics. The double-slit experiment is a classic physics experiment first performed in the early 1800s by the English scientist Thomas Young in an attempt to resolve whether light is a particle or a wave. The fact that light sometimes behaves as a wave and sometimes behaves as a particle is known as the *wave-particle duality*. Subatomic particles like electrons exhibit a similar wave-particle duality.

With the **Science Center To Go Double Slit experiment** our team is making an attempt to simulate this experiment in the classroom setting. Your feedback – through the following questionnaire – will help us to develop and improve this system in order to help all students to understand the physics concepts behind the specific experiment and its results. So we are kindly asking you to devote 15 minutes to answer carefully the following 6 questions.

Question 1:

1. The diagram below shows a top-view of a double-slit arrangement.
   a. According to the particle model of light, draw the expected shadows.

   b. Now, according to your lab observations, sketch the pattern actually observed.

   c. Explain what was happening to the light to produce the dark and light bands. Why does the particle model inadequately explain what is observed?

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Question 2:

Based on your understanding of the wave model of light, predict the pattern you would see from a laser shining through a single, vertical slit. Sketch and explain your prediction.

Question 3: In the double slit diffraction experimental device, we observed a pattern of light that not only gave us evidence that light behaves as a wave, but allowed us to calculate the wavelength of light in air.

a. State how the double slit experiment supports the wave model of light as opposed to the particle model of light.

b. Outline how we used the double-slit diffraction pattern to calculate the wavelength of light (or of a particle) in air.

Question 4: Complete the wavefront diagrams below showing how diffraction will occur differently in each case.

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Question 5:

In one experiment electrons are travelling from a source to a detecting screen, through a double slit.

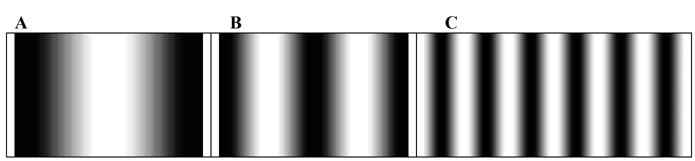
In a second experiment light is travelling from a source to a photographic plate, through a double slit.

In a third experiment marbles are travelling from the source to an array of collecting bins, through two slit-like openings, side by side.

The right-hand figure shows the experimental set-up and the figures below show roughly the possible patterns which could be detected on the various screens.

Top view of experimental set-up not to scale

Possible Patterns (not to scale)



A through C represent some patterns which might be observed. If you think that none is appropriate, answer D.

Which pattern would you expect to observe when,

____1. light passes through the double slit?
____2. marbles pass through the double opening?
____3. electrons pass through the double slit?
____4. light passes through the apparatus when one of the slits is covered?
____5. electrons pass through the apparatus when one of the slits is covered?

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Question 6:

In what way do electrons behave like light? Support your answer with evidence.

In what ways are electrons different from light? Support your answer with evidence.

THANK YOU FOR YOUR HELP!

The Science Center To Go Development Team

6.7 Appendix C SEMI-STRUCTURED INTERVIEW TEMPLATE

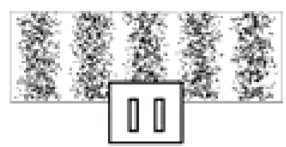
Science Center To Go

Dear Colleague,

These are the Interview **Guidelines** for **the Double Slit Miniature Exhibit**. This interview includes two main questions that will help us to investigate the consistency of students' perspectives across contexts by comparing students responses to the essay question on the double slit experiment (A) with a statement regarding the position of an electron in an atom (B). The interview has to take place following the realization of the experiment. **It is important to make notes and provide us with the explanations of the students selections.** The process for implementing the proposed activities in the classroom are described in detail in the **Science Center To Go Double Slit Pathway**.

A. Please describe the following experiment to the student.

You shoot a beam of photons through a pair of slits at a screen. The beam is so weak that the photons arrive at the screen one at a time, but eventually they build up an interference pattern, as shown in the picture at right.



Please ask the student: What can you say about which slit any particular photon went through?

A. Each photon went through either the left slit or the right slit. If we had a good enough detector, we could determine which one without changing the interference pattern.

B. Each photon went through either the left slit or the right slit, but it is fundamentally impossible to determine which one.

C. Each photon went through both slits. If we had a good enough detector, we could measure a photon in both places at once.

D. Each photon went through both slits. If we had a good enough detector, we could measure a photon going through one slit or the other, but this would destroy the interference pattern.

E. It is impossible to determine whether the photon went through one slit or both.

Please ask the students to explain his/her selection. In case the selection is D please ask for explanations of the sentence "*this would destroy the interference pattern*". Please provide us with the student's explanations:

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B. Please present the following statement to the student:

An electron in an atom has a definite but unknown position at each moment of time.

Ask them to select one of the following options:

I strongly agree
I agree
I am not sure
I disagree
I strongly disagree

Please ask the students to explain his/her selection. In case a student disagrees with the statement above while he/she has select D as the correct question in A part we would like to ask you to ask for further and detailed explanations. Please provide us with the student's explanations:
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THANK YOU FOR YOUR HELP!

The Science Center To Go Development Team

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