Expedition Mundus: a very broad range of school children do science in a classroom game

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Abstract

Expedition Mundus is a classroom game for all children from 8-16 years. The game is played by collecting information, exchanging data, and publishing reviewed conclusions, which simulates language, natural sciences, mathematics and social sciences. In all of the hundreds of tests in schools at all levels the children played the game enthusiastically and led to reflection on the processes of inquiry, discovery and learning – in short, the essence of science.

The game was designed and produced by The Young Academy of the Royal Dutch Academy of Arts and Sciences and De Praktijk, an educational company. Expedition Mundus has been available for two years in Dutch both as complete game boxes and as printable downloads. From mid 2014, an English translation is available mondially at no charge for further local translations (see www.expeditionmundus.org).

We targeted children of all ages and levels, for whom critical thinking-and-doing and creativity are important skills regardless of whether they will become scientists. As such we believe that we help bridge the growing gap between higher-educated and lower-educated people in society. After extensive testing we identified four key reasons for the success of the game. First, no-one has foreknowledge so no-one has a head start. Second, the game is adaptive to heterogeneous cognitive levels. Third, the game has very few rules and many similarities with science. Fourth, the game and the manual for teachers are a detailed starting point for reflection, discussion and follow-up activities.

Introduction

Children are curious and actively interrogate their reality by inquiry, testing hypotheses from statistics and from informal experimentation, and they also learn from watching and listening to others. This is strikingly similar to how scientists learn and many related similarities have been demonstrated (see Gopnik 2012 for a review). Underlying attitudes and skills include curiosity, logical and critical thinking-and-doing. This is not merely important for cognitively more talented children (regardless of how this is defined). Rather, it is important for all children to prepare flexible strategies rather than a set of facts for their daily life in a complex world. For example, we benefit by having one or more strategies to formulate and address questions about choosing healthy food in the supermarket, using medicine, and using and choosing technology, whether it involves improving crop yield, helping to prevent a pandemic, or repairing a bicycle. It is therefore important to society to allow school children to develop scientific attitudes that come naturally to them.

However, in many countries formal education discourages such active attitudes, whilst opportunities in informal education such as the home situation and science museums are inefficiently used by a minority. This is an endemic problem in many educational systems that focus mostly on the reproduction of facts rather than higher-level categories in Bloom's classification. Here, 'system' includes primary and secondary schools, requirements for degrees for educators, legislation and financial incentives that steer school directors, and national exam programs, and consequently the educational materials including books that are tuned to such exam programs. This complex problem

is increasingly recognised by teachers, scientists and industry because problem-solving strategies and creative skills in new applications of knowledge are essential to science, are highly valued as 21st century skills and, arguably, must have been important skills in the entire history of mankind.

To help teachers and pupils rekindle and develop such attitudes we conceived the classroom game Expedition Mundus. The game has proven to be an efficient and stimulating tool to initiate positive developments in schools, in higher education and at the national Ministry of Education. Furthermore the game lubricated the connections between science hubs at most Dutch universities and primary schools (but note that we do not claim it to be a solution for the above problems). We therefore produced a translation into English for global translation and use at no cost and limited restrictions. Below we first describe the game and the ideas and principles underlying the design. We then elaborate how it has been used in primary and secondary education in the Netherlands. Finally we describe how we disseminated the game amongst schools and higher education for teachers and discuss the effectivity of this approach.

Description of the game

Expedition Mundus is a puzzle and role playing game, in which the players have to find the answers to research questions and publish them. Answers to more complicated questions yield more points. Whoever has the most points wins, whilst the whole group acquires more knowledge and understanding of planet Mundus.

The educational module consists of, in its most basic form, little more than the game. No introduction is needed other than the game instructions and, for the younger ages, the introductory read-aloud story. Expedition Mundus contains research questions, information sources and answers to the research questions. Game materials are prints on paper (Figure 1). The information sources are small posters; research questions and answers are on cards. Table 1 contains an overview of the available information sources; table 2 contains an overview of the distribution of research questions per subject for each level. Students collect research question cards from the teacher, and move around the classroom to look at information source posters. When they think they know an answer, they go back to the teacher for peer review; if the answer is approved, the students are

allowed to publish their answer card on their publication sheet. This answer card provides new information for players to use.

Figure 1

Apart from the actual game materials, a teachers' manual was produced that contains instructions for playing the game in the classroom; all the 'facts' about Mundus and the Mundians; a basic analysis of the similarities and differences between playing the game and doing science; instructions for possible follow-up activities, among which making up and drawing new Mundian animals; writing a research report that a Mundian scientist could have written about the students' neighborhood; a basic scientific experiment following the empirical cycle in which students investigate the effect of eggs in a pancake recipe; and two stories (an introduction and a wrap-up) to be read aloud to younger students. After the game, teachers have a structured classroom conversation with their students. In this conversation they ask the students to tell about their experiences,

and link those to short explanations of important aspects of scientific practice. For the younger ages, teachers read the wrap-up read-aloud story and use that to explain a few core competencies for scientists. Then they reflect on scientists, using a quiz supplied in the manual.

Core design aspects

Expedition Mundus was designed at four interdependent but separate functional layers. The first layer is that of the educational material, the second is that of the simulation of scientific practice, the third layer is that of gaming, and the fourth is that of the story of an unknown, fictitious world for reasons explained below. All of these layers are essential to the end product. To ensure high quality at all levels we formulated a number of core design aspects. These are discussed in detail below to illuminate the qualities of the game and to aid future development of science and technology teaching modules.

Education quality: catering to heterogeneity

In a very early stage we decided that the educational materials should teach children about the 'essence of science' rather than about specific scientific content. In other words, it is not about facts but about the process of gaining knowledge. To stimulate all players to participate we eliminated dependencies on pre-existing knowledge by making Expedition Mundus entirely fictitional (see Table 1 for the fictitional information the children have to use).

Table 1. Information sources

Source name	Form	Basic subset
01 Village scene	Illustration of a village with Mundians doing things and talking	x
02 Mealtime scene	Illustration of a Mundian family having a meal at home and talking	x
03 School scene	Illustration of a classroom with Mundian children and a teacher	x
04 Cross section hills	Illustration of a cross section through layers of soil	x
05 Plants in three seasons	Illustration of Mundian plants in three seasons	x
06 Page from biology book 1	Illustration of a spread from a Mundian biology textbook	x
07 Page from biology book 2	Illustration of a spread from a Mundian biology textbook	x
08 Slip dok dok excavation	Illustration of an excavation from the 'slip dok dok' era	x
09 Slip kara excavat ion	Illustration of an excavation from the 'slip kara' era	x
10 Document X1	Illustration of an ancient document with Mundian writing	
11 Document X2	Illustration of an ancient document with Mundian writing	
12 Ringfly and shellbeast numbers	Diagrams of animal numbers	
13 Weather chart 1	Graph of weather data	x
14 Weather chart 2	Graph of weather data	
15 Weather chart 3	Graph of weather data	
16 Distribution shellbeasts	Distribution map of shellbeasts	
17 Distribution ringflies	Distribution map of ringflies	
18 Vegetation map	Map with coverage diagrams of plants	
19 Food web	Diagram of Mundian food web	
20 Report accompanying Mundian for 40 days	Table of activities	
21 Numeral system	Table of Mundian number symbols and their translations	x
22 Sums	Illustration of Mundian sums in an arithmetic notebook	x
23 Words and symbols	List of spoken Mundian words and their translations; list of written Mundian symbols and their translations	x
24 Observations shell beast behavior	Table of behavior codes and tables of observed behaviors	
25 Experiments	Descriptions of 6 performed experiments and results in diagrams and tables	
26 Distances between towns	Table of distances between towns in Mundian units	x
27 Notes on an interview	List of remarks about an interview with a Mundian	
28 Timeline	Diagram of a historical timeline	x
29 Map	Map of Mundus	x

This means that the game is suitable for all age groups and knowledge levels, and that there is no advantage for children who know more than others.

Expedition Mundus covers a wide range of subject areas in science and the humanities: arithmetics, physics, earthscience, biology and ecology, history and

archeology, culture and language. This means that the game can be connected to, and played in, classes in all these school subjects. Furthermore, there is also variation in cognitive load for the students. The research questions come in four levels of increasing difficulty. Moreover, the sources present information in various ways with different levels of abstraction as drawings, diagrams, text, and graphs, which challenges children to test hypotheses from inquiry and statistics. All this variation offers children opportunities to show different talents. The fact that Mundus is an educational game rather than a traditional educational module is also a core design criterion, because a good game stimulates the intrinsic motivation of children to play and win so that learning is automatic. Extracurricular educational material requires that it is simple to prepare and lead by teachers and has a clear teacher's manual. In order to connect it to other classes the manual is also clear about learning goals and facilitates follow-up lesson suggestions.

Table 2. Research question cards

Difficulty level	Arithmetic/math	Physics & earth sciences	Life sciences	History / culture	Language	Total
Basic level	6	11	15	12	6	50
Level 1	8	12	17	6	8	51
Level 2	6	10	8	15	18	57
Level 3	2	3	14	8	6	33
Total	22	36	54	41	38	191

Science simulation quality

The learning goal of the game is to teach children about scientific practice. As the game simulates a scientific expedition with the students as scientists, students will learn about important aspects of science implicitly by doing. After the game, the aspects are made explicit by the teacher, and similarities and differences (shortcomings of the simulation) are discussed.

We emphasised the following aspects of scientific practice: an enquiring attitude, reviewing of methods and research results by other scientists, sharing and publication of research results, and the building on existing published and peer-reviewed knowledge. Furthermore aspects of practising scientists emerge in the game, such as cooperation and competition, and specialisation in disciplines. For the youngest children the explanation

is simplified to focus on qualities a scientist must have, qualities that the protagonists of the read-aloud stories also have: being curious, knowing a lot and solving puzzles.

Clear similarities between science and Expedition Mundus are that more difficult answers earn more points to simulate that these are published in more important journals with higher impact, which is something to compete for. Moreover, the more difficult questions always require combination of sources of information and often require logical inference across different disciplines. The availability of a series of related questions within a single discipline also promotes specialisation because this leads to rapid publication and effective building up of knowledge – as in science. Interesting social behaviour emerges in that children sometimes collaborate alone or in pairs throughout the game but also, when allowed, have temporary alliances and freely exchange information, as scientists do at conferences. An important difference between Expedition Mundus and real science is that the questions are already given, all answers are known unlike in real science, and only one answer to each question is correct.

Game quality: strict editing

A game only works well if it is good as a game in the sense that it is graphically attractive, inviting and exciting. We identified several properties of a good game. Firstly, a good game is easy to learn. That means that the rules had to be clear and not too complicated. For a competitive game this also means that winning has to be unambiguous. As children are very sensitive to fair play, the game should be perceived to be just, which was ensured by eliminating the advantage of pre-existing knowledge and providing variation in questions and sources as discussed above. Furthermore, clarity and a sense of honest gameplay was also ensured by very strict editing of questions and high-quality illustrations, double-checking of answers and ensuring that information sources and published answers provide sufficient information to answer higher level questions.

Finally, the information we aim for children to learn is not presented in a separate game layer that can be skipped at will or when a player is in a hurry. In the case of Expedition Mundus, when a player wants to win the game, they will have to employ a strategy that combines a number of the aspects of science we want them to learn.

Story quality: rich, consistent, open ended

Curiosity drives scientific research. Therefore the Mundus world is rich in details that children would want to know more about. Some of these details are obvious in the illustrations, but much more interesting is hidden below the surface and can only be discovered by combining information and drawing logical inferences. To ensure this story quality, painstaking attention was paid to the internal consistency of Mundus and its people. Language, arithmetics, anatomy, history and culture are all interwoven on Mundus, as they are in real life.

Take, for example, the special significance of the climb-up flower for the Mundians. While playing the game, students will find out that 150 years ago, a volcano erupted on Mundus, plunging it into a 'dark era.' In this dark era, food was less plentiful and the climb-up ceased to blossom since it needs sunlight for that – another fact the students may discover. The sighting of the first new climb-up blossom hailed the start of the 'current era,' including a new year zero. Nowadays, Mundians decorate their houses with stylized paintings of the sun, which is painted the same way as a climb-up flower: a yellow circle with four yellow triangles radiating from it. Those four yellow triangles are by themselves also used for decoration and have acquired a new meaning as the number 144, which is written as four triangles. One triangle represents the number 36 in the base-6 numeral system that the Mundians have because they have six fingers.

Finally, the story of Mundus is open ended. This is literally the case in the wrap-up read-aloud-story that ends with one of the protagonists descending into a mysterious tunnel. It is also the case figuratively, as the strange language invites children to think up new words, the biology invites them to create new animals and plants, and so on. The teachers' manual offers activities to tap into this potential for creativity.

Dissemination in the Netherlands and beyond

Given our goals with Expedition Mundus, the dissemination targeted specific groups and institutions. To value the numbers of distributed games, a reference is here given in the number of elementary schools (ages 6-12) in the Netherlands, which is about 8000, each of which has on average about 220 pupils. This means that about 1.5 million children in the Netherlands are enrolled in primary education. We distributed a total

number of 1500 games for primary education and another 1500 for secondary education, directly and indirectly as follows.

To ensure expert involvement, follow-up activities in science education and geographic spread in the dissemination of the game, we distributed a large number through ten so called 'science hubs' that many Dutch universities have. These offer science education programs for schools with children in the age range of 6-14 and sometimes 6-18, and thereby provide a connection between schools and university in the region. Expedition Mundus proves to be a valuable addition to the portfolio of the science hubs, who use it as a start for science and technology teaching and professionalisation of teachers. On a national level, 180 games were sent to institutions for the education of primary school teachers. Furthermore individual teachers and others could order the game through an online order form, that was checked for legitimacy. Through these channels games were distributed to 761 secondary schools of all educational levels, 354 primary schools (who are also reached through the science hubs), 24 institutions for primary school teacher education, 15 insitutions for higher education, 7 education advisors and services and a few others, among which a scouting group. Finally, around 150 games were distributed through our own networks; at conferences, to media, to government institutions and to scientists. No statistics are known about digital downloads. The game has been available in Dutch since early 2011. From mid 2014, it is available free of charge in English for further translations around the world. See also http://www.expeditionmundus.org.

We qualitatively investigated whether the game fulfilled the design goals and the operational goals from our own field testing, done more than hundred times in different classes and schools at the full range of levels, and from about the same number of informal reports from the science hubs and individuals. Surprisingly, the reports are unanimously positive about the quality of the game and the consistency of the story of Mundus, which are two core criteria. The game design process itself was done under review by an advisory board of scientists from a wide range of scientific disciplines, including didactics and philosophy of science, which ensured that the core design criterion of simulating science was also fulfilled. The core design criterion of simulation of scientific practice is more difficult to test. There are currently two investigations going

on in different regions of the country to measure the science attitude of children before and after playing the game. Furthermore most science hubs are using the game as an initiation part of a larger program of professionalisation of teachers and science education for future teachers, and are measuring the changes in attitude and self-afficacy of these professionals before and after such programs. One important observation was that teachers engaged on the game and other science educational materials emphasising active experimentation by children much more easily when supported by a trainer or a scientist who already has experience with the game and other materials, and after such a supported lesson teachers often continued playing the game in their classes on their own. The effect of the game itself cannot easily be isolated quantitatively from the effect of the entire training. Regardless of quantitative measurements, there is overwhelming anecdotal evidence that Expedition Mundus is fun, like science, stimulates curiosity and the asking of questions, as in science, and is conducive to further development of science education for all children older than about 7 or 8.

Conclusions

We designed the classroom game Expedition Mundus that allows children to be curious and actively interrogate their reality by inquiry, testing hypotheses from statistics and from informal experimentation, and to learn from watching and listening to others. This simulates the process of science in many ways. The game has successfully been used in the Netherlands to improve science education, and is now available mondially.

Acknowledgements

Many people have contributed to Mundus with their expertise, including but not limited to C.L. Geraedts (Vrije Universiteit Amsterdam), C.S. Vlek (Groningen University), Y. Matteman (Naturalis Biodiversity Center), M.J. Jansen (De Praktijk), E.A. Crone (Leiden University), T.J.A.M. van Gog (Erasmus University Rotterdam), M.J.T.H. Goumans (Leiden University Medical Center), A. Sluijs (Utrecht University), O. Gelderblom (Utrecht University), I. Koopmans (Royal Netherlands Academy of Science and Young Academy), M. van der Putten (Royal Netherlands Academy of Science and Young

Academy). Funding for the production was provided by the SNS REAAL Fonds.

References

Gopnik, A. (2012), "Scientific Thinking in Young Children: Theoretical Advances, Empirical Research, and Policy Implications" Science, 337, 28 Sept, pp. 1623-1627.