EXTRA-CURRICULAR SCIENCE LABS FOR GIFTED STUDENTS

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Abstract

In the past couple of years numerous extra-curricular science laboratories (‘school labs’) have been established, their main objective being to attract school students to science and technology. The DLR_School_Lab Oberpfaffenhofen, operated by Germany's national research center for aeronautics and space, DLR, is a typical example for such a science lab. Apart from hands-on experiments offered for students, one of its key activities is the education of teachers.

In this paper the basic concept of an extra-curricular science lab is presented, as well as the special concept of the DLR_School_Lab and its strong ties to state-of-the-art-aerospace research and technology. The lab’s great expertise from numerous high-level enrichment projects for highly talented secondary school students is described. Furthermore, its teacher education concept and capabilities with respect to gifted education is demonstrated. Finally, results from internal and external evaluations are presented which indicate the successful operation of extra-curricular science labs.

Introduction

In Germany there is presently a lack of about 100,000 engineers and about 50,000 IT specialists, the corresponding numbers for Europe are about a factor of ten higher. Attracting talented young people to science and technology is, therefore, a societal task of utmost priority (see e.g., c.f. Heller 2007 and 2008, Heller & Ziegler 2007).

The existing educational system cannot fulfill this task appropriately: In the fields of science and technology regular curricula cannot provide sufficient information and motivation. Because of this lack of information at school, many secondary school students - even at the end of school - are not able to decide about their future study or professional goals. The situation is even more difficult for gifted students because their talents often allow for a greater number of different choices.

Due to the fact that gifted students often are underchallenged by regular school lessons, their great potential is not used or stimulated appropriately. Gifted youth are not per se motivated to make use of their talents, they rather loose interest and motivation by being educated at a low intellectual level.

Especially for this group it is extremely helpful if they come into close contact with demanding professional situations of engineers and scientists: They get the chance to incorporate the role of a researcher in the frame of a science project and cope with institutions involved in research and development.

In order to attract young people to science, technology, engineering, and mathematics (STEM) and make them interested in the respective university disciplines, in the last decade

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many extracurricular science labs have been established by research centers and universities all over Europe, more than two hundred thereof in Germany (LeLa n.d.).

In a typical school lab students are enabled to perform high-tech experiments autonomously and in their own responsibility. The didactical concept is based on a methodology called ‘Inquiry-Based Science Education’ (IBSE) which has recently been recommended by the Euopean Commission (2007), however, it had been developed five decades ago by Martin Wagenschein (1962 and 1980).

In order to achieve a sustainable impact, the typical one-day-visit to a school lab must necessarily be complemented by the mathematics and science teachers. They have to interconnect high-tech experiments and research, on the one hand, and the standard curriculum and school lessons on the other hand. This requires respective skill enhancement and advanced teacher trainings in which the link between extracurricular activities at the school lab and the standard school curriculum is established.

Another aspect of high importance is the verification of a sustainable impact of such extra-curricular measures and offers, i.e. the students’ experimental visits as well as the teacher trainings have to by thoroughly evaluated.

In this paper, the DLR_School_Lab Oberpfaffenhofen is presented as a typical extra-curricular science lab in the context of DLR’s research center Oberpfaffenhofen, including its regular offers for secondary school classes. Second, the school lab’s methods of talent development are described, including several practical examples of enrichment projects. Third, the concept and practical experience of teacher trainings – especially with respect to gifted education – are demonstrated. In the latter sections, feedbacks of students and teachers, respectively, are presented, as well as the hitherto existing results of evaluation studies.

The DLR_School_Lab Oberpfaffenhofen – an extra-curricular science lab

The German Aerospace Center DLR

DLR(n.d.) is Germany's national research center for aeronautics and space. Its extensive research and development work in aeronautics, space, transportation and energy is integrated into national and international cooperative ventures. As Germany's Space Agency, the German federal government has given DLR responsibility for the forward planning and implementation of the German space programme as well as international representation of Germany's interests.

Approximately 5,700 people work for DLR; the center has 29 institutes and facilities at 13 locations in Germany. The DLR site at Oberpfaffenhofen near Munich, employing about 1,500 people, is one of Germany’s largest research locations. The main activities of the five institutes in Oberpfaffenhofen are devoted to space missions, climate research, development of earth observation systems and technologies, the European space-based navigation system Galileo, and to robotics and mechatronics. These activities are complemented by two space operation centers, research flight operations and the German remote sensing data center.

The DLR_School_Lab Oberpfaffenhofen

Since a couple of years the German Aerospace Center DLR operates six extra-curricular science labs, one of which is the DLR_School_Lab Oberpfaffenhofen (n.d.). This science lab offers high-tech experiments to secondary school students which are based on the core research areas and technology fields of the DLR institutes in Oberpfaffenhofen and the authentic research atmosphere of a large-scale research center (Hausamann et al. 2008). The students experience the fascination of aerospace research and become acquainted with the areas as well as with the working method of high-technology research. The DLR_School_Lab presently offers eleven experiments: Infrared, laser, and radar technology, environmental spectroscopy, meterology, analysis of satellite-based earth observation data, satellite navigation, robotics, virtual mechanics, flight-team simulation, and mobile rocket research.

In a typical one-day visit to the DLR_School_Lab, each student can perform two of these experiments corresponding to his or her personal scientific interest. Each experiment comprises two hours of intense activites and experimentation in the respective technology field, therefore, by the end of the day, the student has gained insight into two research areas and their respective working methodologies.

The experimenting students are supervised and supported by DLR scientists as well as university students, however, in principle they are stimulated to work independently and self-regulated to compile new knowledge and expertise about backgrounds, physical, technical and geoscientifical interrelations, and applications of the respective science and technology. They work in small groups of four to five students which generates a stimulating working atmosphere as well as it ties them together as a team.

The key success factor of this extra-curricular science lab is the autonomous and responsible handling of modern and, mostly, valuable state-of-the-art high-tech devices, which are not available at school. E.g. the students are allowed to operate a surface spectrometer, an infrared camera, mobile laser and radar systems, or work with sophisticated simulation programs.

The standard visit to the DLR_School_Lab Oberpfaffenhofen is, in general, complemented and completed by a visit to the German Space Operation Center (GSOC) and to the recently opened Galileo Control Center, which provides insight into the control of satellites, the research activities on the international space station ISS as well as the operation of Europe's future satellite navigation system.

Since its opening in 2003 more than 7,500 students have experimented in the DLR_School_Lab Oberpfaffenhofen.

Assessment by students

Internal and external evaluations are necessary measures to investigate the sustainable effect of extra-curricular science labs. The DLR_School_Labs' standard internal evaluation tools are anonymous questionnaires and oral statements. At the end of a visiting day both types of feedback are requested from each participating student. According to several thousand questionnaires and statements more than two-thirds of the students would like to visit the lab once more. This result is confirmed by an extended external evaluation performed by the Leibniz Institute for Science Education at the University of Kiel, Germany (Pawek 2009). Another questionnaire addressing students who left school in 2008 (and who had visited the DLR_School_Labs in the past years) shows strong evidence that the study decisions of numerous (up to 50%, depending on the individual school) former school students have strongly been influenced by their DLR_School_Lab experience.

Offers for gifted students

Acceleration and enrichment are proven measures to foster gifted students. For this purpose, Renzulli and Reis (2002) have developed the so-called Schoolwide Enrichment Model (SEM), which is especially appropriate to overcome the limits of school curricula and opens the door to the fascination of science and research beyond. This, however, requires the cooperation of schools with experienced research partners, who are able to communicate the enthusiasm for their respective discipline.

One of the key objectives of the DLR_School_Lab Oberpfaffenhofen is the promotion of specially gifted young people (Hausamann 2005). The lab's experiments, derived from current research activities of the DLR institutes, are adaptable to the potential of, especially, highly talented and motivated students because they don't provide any limits with respect to deepness and complexity. The same holds for the supervising scientists and students, whose personal expertise exceeds even the highest school levels by far. In the past years the DLR_School_Lab Oberpfaffenhofen has developed, conducted and successfully completed about 30 special projects and events for highly talented students. In principle, there are two possibilities for such projects:

1. Regular visits to the DLR_School_Lab:

The science content of school lab experiments can be used to extend the regular curriculum, i.e. the standard content of school lessons. The scientific content as well as the range of activities of the respective DLR_School_Lab experiment can be adapted to the special conditions and requests of talented students,

- On the one hand by 'rejuvenation': Gifted students might be able to perform complex experiments at a much younger age than regular students: A typical example is the mechatronics experiment ASURO (n.d.) which comprises assembling and programming a complete robot rover and which is, therefore, only suitable for high school students of age 16 and above. Numerous highly gifted students have successfully assembled the robot at much lower age, down to age 12 (c.f. Hausamann 2005).
- On the other hand by 'extension': When performing an experiment students have the chance to penetrate to very complex levels of the physical theories, they can develop and perform new and sophisticated experimental techniques, or they can design complex programs and analysis methods compared to the standard execution. These options have been utilized extensively by gifted students.

‚Rejuvenation' and ‚extension' are measures corresponding to the standard didactical methodologies of gifted education, namely acceleration and enrichment, respectively. The DLR_School_Lab has gained much of its respective experience from the special classes for gifted students at the Maria-Theresia-Gymnasiums in Munich (n.d.). About 10 of these special classes for gifted students have visited the school lab in the past six years.

Evaluation: Highly gifted students in the DLR_School_Lab Oberpfaffenhofen

The effect of the visits to the DLR_School_Lab Oberpfaffenhofen on gifted students has been investigated by a pilot study conducted by the University of Würzburg (Stumpf et al. 2008). In this study, the feedbacks and questionnaires of gifted students were compared to the respective response of standard classes.

The result of the general assessments of the visits is unambiguously positive for all students. More than half of the students confirm that their respective interest in natural sciences has been enhanced by the visit; nearly every second student intends to aim for a technical or scientific profession.

Obviously, there are no significant gender differences in the feedbacks. This has been figured out for many details such as personal interest, comprehension, introduction to and supervision of the experiments.

Nevertheless, there are significant differences between regular and gifted student groups: E.g. 85% of the gifted, but only 66% of the regular students indicated their interest in another visit of the school lab. The ranking of the individual experiments is different for the two groups, more difficult experiments ranking higher for gifted students. As an overall result, the feedback of the gifted participants is more positive than that of the regular classes.

However, one crucial question could not been investigated in this pilot study, namely the sustainability of a visit to the school lab. For this purpose a further – and much more extended – study is presently being designed by the authors of the pilot study, in which the long-term effects should be emphasized, as well as the comparison to control groups that did not have the opportunity to visit an extra-curricular science lab.

2. Type-3 enrichment projects:

Renzulli's Schoolwide Enrichment Model (SEM, Renzulli & Reis 2002) provides a practical basis for school programs to identify and foster school students with exceptional abilities and help young people develop their respective talents. Renzulli introduces three types of enrichment activities of increasing complexity and demands:

- Type I enrichment moves students beyond the regular curriculum to potentially exciting new areas of interest.
- Type II enrichment enables students to handle advanced and differentiated topics.
- Type III enrichment is the most advanced stage; it 'involves students who become interested in pursuing a self-selected area and are willing to commit the time necessary for advanced content acquisition and process training in which they assume the role of a first-hand inquirer' (Renzulli & Reis 2002).

Enrichment activities provide opportunities for students to work in a self-directed manner on an applied subject, to develop authentic products, and to achieve an intended impact on a defined target group. These students take over the role of a researcher.

In the past couple of years several type III enrichment projects have been completed in cooperation of the DLR_School_Lab Oberpfaffenhofen and gifted student groups from different locations in Germany.

The following two examples show the distinctiveness and complexity of type III enrichment projects, how highly talented student teams can be occupied with highly interesting questions in current research, and how they are guided from the status of active learners to that of active researchers.

The GPS-Einstein project

Satellite navigation is one of the rare technical applications which is strongly influenced by both Einstein's special and general theories of relativity: Satellite navigation requires a change to the frequencies of atomic clocks on board of GPS satellites in order to synchronize them with the clocks on the ground.

The intention of the GPS-Einstein project (Hausamann & Schmitz 2007) was to investigate quantitatively how much adjustment the satellite clocks require. It was initiated by the DLR_School_Lab Oberpfaffenhofen, based on its expertise in the technical field of satellite navigation.

The overall duration of the project was approximately half a year. It was carried out in the Year of Physics 2005 by a 12th grade physics course at the CJD Christophorusschule Königswinter in Germany. The gifted education concept of this school is characterized by a subdivision of the regular school year into three trimesters. By accelerating and compacting the curriculum, one of the trimesters is available for special enrichment projects. The 12th grade physics course (11 students) of the 2004/5 school year was an ideal group to be stimulated for the GPS-Einstein project in the 3rd trimester:

In the first phase, the students were introduced to Einstein's theory of relativity on the one hand, and to satellite based navigation on the other hand in the frame of a type II enrichment activity: Each of the students had to work on a specific sub-area, such as determination of the speed of light, astronomical methods for navigation, principles of satellite navigation, error analysis and correction, and economic and technological requirements for satellite navigation systems. They subsequently produced corresponding reports and presented the results to the class. These individual activities were supported by the teacher. Furthermore, the students were introduced to the technology of GPS receivers.

The second phase of the project was a three-day excursion to the DLR_School_Lab Oberpfaffenhofen. The program of this visit was tailored to the expected requirements and abilities of a group of exceptionally gifted students. One important didactical feature was a continuous alternation between self-regulated experimental activities and scientific lectures at university level (i.e. much higher than the standard secondary school physics course level). The main focus was an in-depth elaboration of knowledge with respect to satellite navigation science and technology, time standards, atomic clocks and time measurement, and the consequences of Einstein's theories of relativity for navigation satellites. Finally there were several opportunities to discuss the respective subjects among the members of the group, with the supervising students as well as with the navigation experts. This helped define the further steps of the project.

In the third and final phase of the project four of the 11 students, after having returned home from Oberpfaffenhofen, took responsibility for quantitatively investigating the problem, putting everything together, and coming up with answers to the key questions: They derived the frequency shift of the GPS satellite clocks and the consequences thereof. According to the impression of all supervisors, these students represented the top group of the physics course.

These four students demonstrated their final results in the frame of a school festival, including a detailed poster presentation and an experimental demonstration of GPS receivers on the schoolyard. As a further highlight the group was invited to the Students' Congress in Munich in December 2005 to present their final results. This national congress at the end of the Einstein Year of Physics 2005 was devoted to Albert Einstein's life and research.

The project geophysics – remote sensing from satellites

One of the most important methods to identify changes of the environment is called ‚change detection': Satellite data acquired at different times are compared in order to quantitatively analyze changes caused by natural or human impact, such as sealing of the soil surface by settling activities, environmental damage, or natural catastrophes. At school this complex method has so far only been applied in special geography courses at the top secondary school classes.

The goal of the enrichment project 'geophysics – remote sensing from satellites' was to investigate the changes of the participants' home environment by studying the properties of the solar radiation spectrum and its influence on the geosystem and by analysing remote sensing data from satellites (Hausamann et al. 2007).

The project was initiated conjointly by the Hector-Seminar[2] and the DLR_School_Lab Oberpfaffenhofen. In early 2006 the project was officially announced on the website of the Hector-Seminar (n.d.). The focus groups were 9th and 10th grade students. Ten students from ten different secondary schools applied for the project.

The preparation phase was started with a one-day workshop in April 2006 in Heidelberg, where the students were introduced to the scientific background, methodologies and technologies of satellite based remote sensing of the earth's environment. Furthermore, hardware and software details of the respective School_Lab experiments were introduced. The project goals were discussed and agreed.

The second phase consisted of a visit to the DLR_School_Lab Oberpfaffenhofen: In May 2006 the Hector-Seminar students spent three days in Oberpfaffenhofen. All of them performed the experiments environmental spectroscopy and satellite data. Special attention was given to the operation of DLR's imaging hyperspectral ground spectrometer. Extended practical sessions were focused on the application of two different software programs to access, process, and analyze satellite data. Further subjects were a theoretical course on infrared measurement technology and remote sensing, a guided tour to DLR's Crisis Intervention Center and the robot-operated data archive. The project tasks were defined in detail, the most important being the analysis of changes, based on a comparison of satellite images from 1989 and 1999.

The third project phase was initiated two weeks after the visit to Oberpfaffenhofen. The DLR_School_Lab supervising team went to Heidelberg for a measurement campaign involving all instruments (spectrometers and infrared devices). Further investigations with these instruments provided the students with deeper insights and helped them answer several open questions. Based on information and results from the measurement campaign the students performed the final task of the project: they classified satellite images and analyzed changes to their respective home environment and, finally, produced reports on the results.

End of September 2006 the students presented the Geophysics project at the 2006 Hector-Seminar Project Workshop in Mannheim. Teachers, students and invited guests were informed about the results in oral presentations and posters.

The exceptional work of this group was recently honored with the DLR_School_Lab Price 2008. This price is awarded every year by the Society of Friends of DLR, based on a proposal of DLR's Executive Board.

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[2] The Hector-Seminar (c.f. Heller 2008a) is a program to foster highly gifted secondary school students by providing enrichment activities in the areas of mathematics, informatics, natural sciences and technics. It is financed and supported by the Hector Foundation. The Hector-Seminar supervises especially gifted secondary school students on a long-term basis throughout their school career. The seminar program supplements the regular school activities, from the 6th grade to the end of secondary school at the 13th grade. The projects are of interdisciplinary character, the main objective aiming to facilitate a holistic development of personality, the activation and evolvement of cognitive, methodical, personal, and social potentials, as well as the development of corresponding competencies and capabilities. Each seminar course comprises 60 students who are chosen in a two-stage selection process from all 7,500 6th grade students of the secondary schools in the region of north-western Baden-Wuerttemberg. The first stage selection is a screening process, whereas the secondary selection is based on the Munich High Ability Test Battery developed by Heller & Perleth (2005). The cognitive, creative, and social capabilities of the selected students are far beyond the secondary school average. The seminars are located in the three cities of Heidelberg, Mannheim, and Karlsruhe; they are headed by two teachers each, and are conducted two afternoon hours per week. Presently some 400 students in eight courses participate in the Hector-Seminar.

Students assessment of the type III enrichment projects

The feedback of each individual group involved in the DLR_School_Lab's type III enrichment projects was extremely positive – even if there were distinct points of criticism and substantial recommendations for improvements. The following assessment is quite typical for all of the projects:

On the occasion of a visit to the Christophorusschule Königswinter in May 2006 (i.e. half a year after termination of the GPS-Einstein project) there was an opportunity to talk to the four students of the GPS-Einstein project and their supervising teacher. The students reported that it was at the end of the project that they took over the initiative to finalize the project, i.e. produce the final report and present the results. This final work was quite exhausting, but left a deep and very positive impression. According to the students' conclusion, the project had strongly influenced the study decisions of all four of them – physics, chemistry, information technology, and mechanical engineering.

Teacher Education at the DLR_School_Lab Oberpfaffenhofen

The DLR_School_Lab Oberpfaffenhofen offers advanced training courses for teachers in order to prepare them for the visits of their classes. The main objective of the teacher education is to help them integrate the extra-curricular activities into their standard curricula and, thereby, generate an application oriented concept for classroom education. The school lab offers special courses for teacher groups from individual schools, for regional teacher groups (from different schools), and for advanced trainings of Bavarian seminar teachers, i.e. the instructors of future teachers.

The key elements of the teacher training are self-contained experiments, where the teachers take over the role of their students and experience the same feeling of success when completing an experiment. The experimental work is complemented by didactical as well as scientific background information about the respective experiments and research areas.

In the past five years about 1,000 teachers have attended advanced teacher trainings by the DLR_School_Lab Oberpfaffenhofen. The general feedback of teachers is extremely positive, especially with respect to self dependent accomplishment of high-tech experiments, technical advancement, and stimulations for practical classroom teaching. Many of them have obviously been stimulated to visit the DLR_School_Lab Oberpfaffenhofen with their classes.

A typical example is a one-day external regional advanced teacher training on robotics which took place in Regensburg, Bavaria, in October 2007. The 19 participants built and programmed, altogether, six ASURO (n.d.) robots. The feedback presented in the following table 1 was officially requested by the organizing school administration.

Assessment by the participants	Excellent	Very good	Good	Passing	Fail
Fulfillment of expectations	14	5			
Practical usability of results	6	9	3	1	
Quality of presentation	12	7			
General conditions of course	14	5			

Table 1: Feedback of the participants of the advanced teacher course on robotics

Education of teachers of the gifted

Teachers play a key role in gifted education; their characteristics and necessary competencies have long ago been summarized by Seeley (1985): Especially in type III enrichments the teacher's role changes from that of an educational instructor to that of an initiator, mentor, supervisor, coach, consultant, and assessor of achievements.

Most important is to support the independence, motivation, and creativity of gifted students (c.f. Cropley & Urban 2002). Pedagogical concepts such as open learning (Peschel 2002) or self-regulated learning (Fischer 2004) are ideally suited for type III enrichment projects.

The teacher education concept developed at the DLR_School_Lab Oberpfaffenhofen (Hausamann 2008 and 2008a), interconnecting science labs and the school curriculum, including self-experimentation, science background, and didactical context utilizes all of the methodologies described above and is, therefore, especially suitable for teachers of gifted learners. In addition,

- the scientific background of individual experiments is extended to possible problems and questions of highly interested and talented students,
- possible combinations of different experiments and technologies are addressed,
- and the didactical background to accelerate experiments, i.e. to make them feasible and interesting for younger students, is presented.

A one-day workshop of a group of Hector-Seminar supervisors at the DLR_School_Lab Oberpfaffenhofen in December 2004 is a typical example for such an advanced gifted education teacher course. The feedback was quite enthusiastical, correspondingly the overall mark for this workshop was 'excellent' by six of the seven participants. This workshop was the nucleus of, so far, two successfully completed type III enrichment projects: Geophysics in 2006 (see above) and Satellite Navigation in 2008.

The DLR_School_Lab's extracurricular gifted education concept is also integrated in the so-called ECHA Diploma teacher education courses of the International Center for Giftedness at the University of Münster, Germany (ICBF, n.d.). Since 2007 the potential of extracurricular science labs – such as the DLR_School_Lab Oberpfaffenhofen – in gifted education is presented as part of the pratical education block, the main focus being the conception of type III enrichment projects and stimulating recommendations and proposals. Additionally, the DLR_School_Lab has been appointed an official location which can be visited for observation of gifted student courses; two of such observations are mandatory for each ECHA Diploma applicant.

Summary and future prospects

An enrichment concept for gifted students has been developed and successfully realized in numerous projects at the DLR_School_Lab Oberpfaffenhofen. The same holds for the gifted education teacher training concept, which comprises especially the scientific and didactical basics for type III enrichment projects at pre-university school level.

The success of these activities is confirmed by evaluations. However, with respect to the long-term impact and sustainability further studies are required.

The enrichment projects have practically demonstrated how school students, by working with scientific subjects far above school level, transform from learners to researchers. The transformation of concepts such as 'self-regulated learning' to a corresponding concept of 'self-regulated research' would certainly help to describe the crossover of gifted young people from school to university. In this transformation process, the spatial, social, and formal boundaries of the classroom situation is dissolved, problems are no longer bound to the known, thus requiring new processes of cognition. The theoretical description of the transition from a gifted learner to a gifted researcher should become an issue for giftedness research.

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