3. 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 in Germany, whose main objective is to attract students to science and technology. The German Aerospace Centre (Deutsches Zentrum für Luft-und Raumfahrt, DLR) School Lab Oberpfaffenhofen, operated by Germany's national research center for aeronautics and space, is a typical example of such a science lab. Apart from a variety of hands-on experiments offered for students, its key mandate is teacher education. In this paper, the basic concept behind extra-curricular science labs is presented, as illustrated by the DLR School Lab and its strong ties to state-of-the-art aerospace research and technology. The lab's expertise is described, based on numerous, high-level enrichment projects for highly talented secondary-school students. Furthermore, the model of teacher education with respect to giftedness is demonstrated. Finally, results are presented from both internal and external anecdotal evaluations, which support the success of the extra-curricular science labs.

Currently, in Germany, there is a serious lack of engineers and information technology specialists. This situation is 10 times more critical for Europe. Attracting talented young people to science and technology is, therefore, a national priority (Heller 2007, 2008; Heller & Ziegler, 2007).

The existing educational system cannot meet the demand. The regular science and technology curricula in secondary schools provide neither sufficient instruction nor student motivation for students to pursue this field. Because of this lack of exposure, many secondary-school students—even upon graduation—are undecided about their future studies. Options are even more limited for gifted students because the opportunity to use their talents is not made available to them, and their potential is lost. Since gifted students are often under-challenged by regular school lessons, they soon lose interest. It is important for them to experience real-life applications typically faced by engineers and scientists and assume the role of researcher working within the framework of an authentic science project within institutions involved in research and development.

In the last decade, in order to attract youth to Science, Technology, Engineering, and Mathematics (STEM), numerous extra-curricular science laboratories have been established by research centers and universities all over Europe. More than two hundred such labs exist in Germany, alone (LeLa, n.d.). In a typical school lab, students are able to perform high-tech experiments independently through what is called Inquiry-Based Science Education (IBSE), a technique recently recommended by the European Commission (2007). This technique was developed by Martin Wagenschein (1962, 1980).

In order to achieve a sustainable impact, the typical one-day visit to a school lab must be complemented by the teachers' regular mathematics and science lessons by linking the high-tech experiments and research to the standard curriculum. This requires advanced teacher training and enhanced skill development. Another important element of the extra-curricular science labs is ensuring the sustainability of its impact for both teachers and students.

In this paper, the DLR School Lab Oberpfaffenhofen is presented as an example of an extra-curricular science lab, including its regular offerings for school classes. The school lab's methods of talent development are described, including several practical examples of enrichment projects, as well as the concept and practical experience of teacher training, especially with respect to gifted education. Additionally, student and teacher feedback on their experiences are presented, as well as the 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 has resulted in numerous national and international cooperative ventures. As Germany's space agency, the federal government has given DLR responsibility for the planning and implementation of the German space program, as well as representing its interests internationally.

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

The DLR School Lab Oberpfaffenhofen

Since 2000, the DLR has operated six extra-curricular science labs, one of which is the DLR School Lab Oberpfaffenhofen (n.d.). This science lab offers students high-tech experiments within the authentic research atmosphere of a large-scale research center (Hausamann et al., 2008). Students experience the fascination of aerospace research and become acquainted with methods of high-technology research. At present, the DLR School Lab offers eleven experiments: environmental spectroscopy, meteorology, analysis of satellite-based earth observation data, satellite navigation, robotics, virtual mechanics, flight-team simulation, mobile rocket research, and infrared, laser, and radar technology.

On a typical, one-day visit to the DLR School Lab, each student may perform two of these experiments, based on his or her personal interests. Each experiment involves two hours of intense activities and experimentation in the respective field of technology. By the end of the day, students have gained insight into two research areas and the respective experimental methods.

Students are supervised and supported by DLR scientists, as well as by university students, employed for this purpose. In principle, however, they are encouraged to work independently, to generate new knowledge and expertise about the interrelationships among the physical, technical, and geoscientific fields and their applications. Students work in small groups of four or five, generating a stimulating working atmosphere and bonding as a team.

The key success factor of this extra-curricular science lab is the use of state-of-the-art, high-tech equipment, which is unavailable in the school system; for example, students are allowed to operate a surface spectrometer, an infrared camera, mobile laser and radar systems, and sophisticated simulation programs.

Students' visits to the DLR School Lab Oberpfaffenhofen are complemented by and concluded with a visit to the German Space Operation Center (GSOC) and to the recently opened Galileo Control Centre. The latter provides insight into the control of satellites and the research activities of 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 conducted experiments in the DLR School Lab Oberpfaffenhofen.

Assessment by students. Both internal and external evaluations are conducted to investigate the sustainable effect of extra-curricular science labs. The DLR School Labs' standard, internal evaluation tools are anonymous questionnaires and oral testimonies. At the end of a visiting day, both types of feedback are requested from each participating student. In general, based on a preliminary analysis of several thousand questionnaires and oral statements, over two-thirds of the students indicated that they would like to visit the lab again.

An external evaluation, conducted by the Leibniz Institute for Science Education at the University of Kiel, Germany (Pawek 2009), confirmed these results. A different questionnaire addressing students who left secondary school in 2008 (and who had visited the DLR School Labs in past years) shows strong evidence that the future career decisions of numerous former students (up to 50%, depending on the individual school) have been influenced positively by their DLR School Lab experience.

Programming for Gifted Students

Acceleration and enrichment are proven programmatic measures designed for gifted students. Recognizing the limits of school curricula, Renzulli and Reis (2002) developed the Schoolwide Enrichment Model (SEM), whose goal is to overcome the limits of school curricula and promote the fascination for science and research beyond the regular instructional program. This, however, requires the cooperation between schools and 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 gifted youth (Hausamann, 2005). The lab experiments, derived from current research activities at the DLR institutes, are adaptable to the potential of highly talented and motivated students. The labs are not constrained with respect to depth and complexity. The same holds true for the supervising scientists and university students, whose personal expertise far exceeds even the highest school levels. 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, as detailed below.

1. Regular Visits to the DLR School Lab

School lab experiments can be used to extend the regular curriculum. Activities of the DLR School Lab can be adapted to the special conditions and requests of talented students either by acceleration or extension.

Acceleration. Gifted students are able to perform complex experiments at a much younger age than regular students. A typical example is the mechatronics experiment ASURO (n.d.) which involves assembling and programming a complete robot rover—a task suitable only for secondary-school students aged 16 years and over. Many highly gifted students, as young as 12 years of age, have successfully assembled the robot at the DLR School Lab (c.f. Hausamann, 2005).

Extension (depth). When performing an experiment, students have the chance to move to very complex levels of the physical theories involved; they can develop and perform new and sophisticated experimental techniques, and they can design complex programs and analytical methods beyond what is expected by the standard curriculum. Gifted students take advantage of these opportunities. The DLR School Lab has worked primarily with gifted students from the Maria-Theresia-Gymnasiums in Munich (n.d.). About 10 special classes for gifted students have visited the school lab in the past six years.

Pilot evaluation: Highly gifted versus regular 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 the University of Würzburg (Stumpf et al., 2008) in a pilot study. Summary responses of gifted students were compared to those of students in regular classes. Results show that the visits to the School Lab are clearly positive for all students. More than half confirmed that their interest in natural sciences has been enhanced by the visit; nearly every second student plans to pursue a technical or scientific profession.

There were no significant gender differences in the feedback with respect to factors such as personal interest, comprehension, and selection of experiments.

There were significant differences between regular and gifted student groups; 85% of the gifted, but only 66% of the regular students, expressed an interest in making an additional visit to the school lab. The ranking of the individual experiments by the two groups also differed, with the more difficult experiments ranking higher (more positively) for gifted students. Overall, the feedback from the gifted participants was more positive than that from students in the regular classes.

The sustainability of the effect of visiting the school lab, however, could not be investigated in this pilot study because measuring the effect requires a significant lapse of time. A further extended study is being designed by the author to examine the long-term effects of the DLR experience, utilizing a control group of students who will not have the opportunity to visit this type of lab.

2. Type III Enrichment Projects

Renzulli's Schoolwide Enrichment Model (Renzulli & Reis, 2002) provides a practical basis for school programs to identify and nurture the talents of students with exceptional abilities. Renzulli introduces three types of enrichment activities of increasing complexity and demands:

- Type I enrichment moves students beyond the regular curriculum to consider potentially exciting new areas of interest;
- Type II enrichment targets the development of higher-level thinking (problem-solving, critical thinking, inquiry training) and specific learning skills, allowing students to undertake more advanced and differentiated topics; and
- Type III enrichment, the most advanced stage, "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, 2000, pp. 370–371).

Enrichment activities provide opportunities for students to work independently on an applied subject, to develop authentic products, and to achieve an intended impact on a defined target audience. These students assume the role of researchers.

In the past couple of years, several Type III enrichment projects have been completed by gifted student groups from across Germany in collaboration with the DLR School Lab Oberpfaffenhofen. The following two examples show the distinctiveness and complexity of Type III enrichment projects, the extent to which talented student teams can generate highly interesting questions for current research, and the process by which students evolve from "learners" to "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. It requires a change to the frequencies of atomic clocks on the 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 half-year Project took place in 2005, during the Year of Physics, in a Grade 12 Physics course at the Christophorusschule Königswinter (CJD) in Germany. The gifted education model at this school follows the three-trimester system. By accelerating and compacting the curriculum, one of the trimesters is available for special enrichment projects. The Grade 12 Physics course (11 students) in the 2004 - 2005 school year was an ideal group for the GPS-Einstein Project.

In phase one, students were introduced to Einstein's theory of relativity, as well as to satellite-based navigation, in the context of a Type II enrichment activity, and the technology of GPS receivers. Each of the students had to work on a specific sub-area, such as the 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. Subsequently, students produced reports on their topics and presented their results to the class. These individual activities were all supported by the teacher at the students' secondary school.

Phase two of the Project consisted of a three-day excursion to the DLR School Lab

Oberpfaffenhofen. The school lab program was tailored to the requirements and abilities of exceptionally gifted students. One important didactical feature was a continuous alternation between independent experimentation and university-level scientific lectures. The main focus was an in-depth examination of 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 for the students to discuss their respective subjects with members of the group, with the navigation experts, and with the supervising university students, who are studying electrical engineering, physics, mathematics, geosciences, biotechnology, food technology, and chemistry, and are employed by the science lab exclusively for advising and career-modeling purposes. The school-lab program helped define the next step of the Project.

In the third and final phase of the Project, four of the 11 students, upon returning home from Oberpfaffenhofen, took responsibility for empirically investigating the problem, synthesizing quantitative information, and generating answers to key questions; for example, they derived the frequency shift of the GPS satellite clocks and the subsequent consequences. According to all the supervisors, these students constituted the top group in the Physics course.

These four students demonstrated their final results, including a detailed poster presentation and an experimental demonstration of GPS receivers, at a festival at their school. 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, which took place at the end of the Einstein Year of Physics in 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 "change detection." Satellite data acquired at different times are compared in order to analyze quantitative changes caused by natural or human impact, such as the sealing of the earth's surface by settling activities (e.g., dust from volcanic eruptions), environmental damage, or natural catastrophes. At school, this complex method has, so far, been applied only in special geography courses in high-level, secondary-school classes.

The goal of the enrichment project, Geophysics—Remote Sensing from Satellites, was to investigate the changes in the participants' home environment by studying the properties of the solar radiation spectrum and its influence on the geosystem and by analyzing remote sensing data from satellites (Hausamann et al., 2007).

The project was initiated jointly by the Hector-Seminar[1] and the DLR School Lab Oberpfaffenhofen. In early 2006, this external, talent-support program was officially announced on the website of the Hector-Seminar (n.d.). The focus groups, typically consisting of 10 students, were highly-talented students from Grade 9 and 10. Students from 10 different secondary schools applied for the project, and each seminar group was supervised by a team of two teachers.

The preparation phase began 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. Hardware and software details of the respective School Lab experiments were presented, and the project goals were discussed and decided.

[1] The Hector-Seminar project (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 technology. It is financed and supported by the Hector Foundation. In the Hector-Seminar, especially gifted secondary-school students are supervised on a long-term basis throughout their school career. The seminar program supplements the regular school activities, from Grades 6 to 13. The projects are interdisciplinary, whose main objective is to facilitate a holistic development of personality, the fostering of cognitive, logical, personal, and social potential, and corresponding competencies. Each seminar course involves 60 students, who are chosen in a two-stage selection process from all 7,500 Grade 6 students of the secondary schools in north-western Baden-Württemberg. The first stage consists of a screening process, whereas the second stage utilizes the Munich High Ability Test Battery, developed by Heller and Perleth (2005), for selecting students. The cognitive, creative, and social capabilities of the selected students are far beyond the secondary-school average. The seminars are located in three cities—Heidelberg, Mannheim, and Karlsruhe. The project at each site is headed by two teachers and takes place in the afternoon, two hours per week. At present, approximately 400 students in eight courses participate in the Hector-Seminar.

The second phase of the project consisted of a visit to the DLR School Lab Oberpfaffenhofen. In May 2006, the Hector-Seminar students spent three days in Oberpfaffenhofen. Supervised by the DLR Lab's university students, all of them conducted the experiments involving the environmental spectroscopy and satellite data. Special attention was given to the operation of DLR's imaging hyperspectral ground spectrometer. Extended practical sessions focused on the application of two different software programs used to access, process, and analyze satellite data. Additional subjects of study included a theoretical course on infrared measurement technology and remote sensing. 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 visit also included a guided tour of DLR's Crisis Intervention Center and the robot-operated data archive.

The third phase of the Hector-Seminar was initiated two weeks after the visit to Oberpfaffenhofen. The DLR School Lab supervising team went to Heidelberg for a measurement campaign[2] involving all instruments (spectrometers and infrared devices). Further investigation with these instruments provided students with deeper insights and more complex explorations in the field. Based on the information and results gained from this measurement session, the students performed the final task of the project. They classified satellite images and analyzed changes in their respective home environments and, finally, produced reports on the results.

At the end of September 2006, the students presented their Geophysics project at the 2006 Hector-Seminar project workshop in Mannheim. Results were shared, orally and visually, through posters, with teachers, students, and invited guests.

The exceptional work of this group was recently honored with the DLR School Lab Prize of 2008. This prize is awarded annually by the Society of Friends of DLR, on the recommendation of the DLR's Executive Board.

Students' assessment of the Type III enrichment projects. The feedback from each group involved in the DLR School Lab's Type III enrichment projects was extremely positive—even though there were distinct points of criticism and substantial recommendations for improvement. On a visit to the Christophorusschule Königswinter in May 2006 (half a year after the termination of the GPS-Einstein Project), four students of the GPS-Einstein Project reported that although preparing their final report and presenting the results was quite exhausting, it left a deep and very positive impression upon them. According to all four students, the project had strongly influenced their career decisions in the fields of 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 school teachers in order to prepare them for their class visits to the lab. The main objective of the teacher-education component at the DLR Lab is to help the teachers integrate the extra-curricular activities within their standard curricula and apply concepts to real-world examples. The DLR School Lab offers special courses for groups of teachers from individual schools or regions. They also offer advanced in-service training seminars for the Bavarian teachers, who will serve as the instructors of future teachers.

The key elements of teacher training offered at the DLR School Lab include both self-contained experiments, as well as lectures. In the former, teachers assume the role of their students, experiencing the same feelings of success upon completion of an experiment as their students do. Lectures are the vehicle by which background information about teachers' respective experiments and scientific research areas are disseminated.

Since 2003, more than 1,000 regular teachers have attended advanced teacher-training courses offered by the DLR School Lab Oberpfaffenhofen. The general feedback of teachers has been highly positive, especially with respect to successfully conducting high-tech experiments independently, developing advanced technical skills, and generating ideas for practical classroom teaching. Many

[2] The term "measurement campaign" means that equipment is shipped to another location to which a group of scientists relocates in order to make local validation measurements for the purpose of verifying analyzed data.

Table 1: *Teacher Participant Feedback on the Advanced Teacher Course on Robotics*

Teacher Participant Feedback on the Advanced Teacher Course on Robotics	Excellent	Very good	Good	Passing	Fail
Fulfillment of expectations	14	5			
Practical usability of results	6	9	3	1	
Quality of presentation	12	7			
Organization, venue, atmosphere	14	5			

of the teachers have been motivated to bring their students to visit the DLR School Lab Oberpfaffenhofen.

An example of advanced training offered to teachers at the DLR School Lab is a one-day regional session on robotics, which took place in Regensburg, Bavaria, in October 2007. Together, the 19 participating teachers built and programmed six ASURO (n.d.) robots. The feedback presented in Table 1 was officially requested by the organizing school administration.

Education of Teachers of the Gifted

Teachers play a key role in gifted education. Key teacher characteristics and competencies have long ago been summarized by authors such as Seeley (1985). Especially, in Type III enrichment activities, the teacher’s role changes from that of an educational instructor to that of an initiator, mentor, supervisor, coach, consultant, and assessor of achievement. The teacher’s most important function is to support the independence, motivation, and creativity of gifted students (Cropley & Urban, 2002). Pedagogical approaches such as open learning (Peschel, 2002) or self-regulated learning (Fischer, 2004) are ideally suited for Type III enrichment projects.

The teacher-education model developed at the DLR School Lab Oberpfaffenhofen (Hausamann, 2008a, 2008b) is especially suitable for teachers of gifted learners because it links the science labs to the standard school curriculum, includes teacher-run experiments, promotes the acquisition of the requisite background science knowledge, and uses the lecture as a method of instruction. In addition, the scientific fundamentals required in individual experiments inspire talented participants who want to tackle more complex problems and questions. Teachers are exposed to different combinations of various experiments and technologies, and they receive relevant, essential information for making experiments more feasible for and interesting to younger students.

A one-day workshop for a group of Hector-Seminar supervisors at the DLR School Lab Oberpfaffenhofen, conducted in December 2004, is a typical example for such an advanced-level training course, specially designed for teachers of the gifted. The goal of the workshop was to create new ideas for the Hector-Seminar projects and became the nucleus, so far, of two successfully completed Type III enrichment projects: Geophysics in 2006 (see above) and Satellite Navigation in 2008. The feedback on the workshop, the first of four since 2004, was enthusiastic and evaluated as “excellent” by the seven participating teachers.

The DLR School Lab’s extra-curricular, gifted education model is also integrated in The European Council for High Ability (ECHA) Diploma teacher-education courses of the International Center for Giftedness at the University of Münster, Germany (ICBF, n.d.). Since 2007, the extra-curricular science labs in gifted education, such as the DLR School Lab Oberpfaffenhofen, have been presented as an option in the education practicum, with the main focus on Type III enrichment projects. Additionally, the DLR School Lab has been designated as an official observation site for students in gifted courses. Two such observations are mandatory for each ECHA Diploma applicant.

Conclusion

This paper explores the basic concept behind extra-curricular science labs, exemplified by the DLR School Lab, with its strong links to state-of-the-art-aerospace research and technology. The described enrichment model for gifted students has been developed and successfully implemented through numerous projects at the DLR School Lab Oberpfaffenhofen. The associated gifted-education, teacher-training model, developed at the DLR Lab, has formed the scientific and didactic basis for Type III enrichment projects at a pre-university level for secondary-school students. The success of these projects has been supported by anecdotal evaluations; however, further studies are required to assess the effects of the projects in terms of their long-term impact and sustainability.

The enrichment projects described in this paper have demonstrated how students, by working with scientific subjects far above the regular school level, are transformed from self-regulated learners to self-regulated researchers. This transformation, effected through their DLR Lab experience, has helped students make the transition from school to university with greater ease, enabled them to gain a more profound understanding of their field of study, and assisted them in making more informed career choices in fields such as physics, chemistry, information technology, and mechanical engineering.

The DLR Lab is one approach by which gifted learners become gifted researchers. Alternative approaches remain the object for further research in the area of giftedness.

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