ENRICHMENT AT THE DOORSTEP OF UNIVERSITY—THE EINSTEIN GPS PROJECT

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Introduction

At the end of school in the transition phase to university, young people usually do not have a feeling for what they can expect from their future. Moreover, they often don't know which profession to aim at and, as a consequence, which discipline to study. For highly gifted students the situation can be even worse, since their talents often allow a greater number of different choices. It is, therefore, vital especially for the gifted to come into close contact with highly demanding professional situations.

Science and technology is such a field where regular curricula often cannot provide this lead. In cooperation with institutions involved in research and development, talented school students should be enabled to incorporate the role of a researcher in the frame of a science project, since this could be extremely helpful for them when making decisions about their future profession and the corresponding discipline at university.

Acceleration and enrichment of standard curricula are appropriate measures to considerably improve the school education of students with exceptional talents. In this context Renzulli and Reis (2002) have developed one of the most successful concepts, the Schoolwide Enrichment Model, its ultimate goal being activities which allow students to overcome the limiting boundaries of school curricula and become fascinated by and involved in state-of-the-art science and research. This requires, however, the cooperation of schools with experienced science and research partners interested in motivating newcomers and helping them come aboard.

The Einstein GPS project described in this paper is a typical example of a challenging subject which can be used to create a corresponding enrichment activity.

Section 2 provides an overview of state-of-the-art giftedness models and explains the concept of Renzulli's Schoolwide Enrichment Model. In Section 3 a short introduction to satellite navigation and Einstein's theories of relativity is given. In Section 4 details of the project are described, as well as the results achieved by the students. Finally, practical advice for teachers is provided in Section 5.

Talent development through Type III enrichment activities

The talent development of highly gifted children is a complex process which can be described by multifactorial giftedness models, e.g., the Multifactor Model of Giftedness (Mönks, 2005) the Munich Model of Giftedness (MMG, Heller & Ziegler, 2002), or further approaches as described in the International Handbook of Giftedness and Talent (Heller, Mönks, Sternberg & Subotnik, 2002) or in Sternberg & Davidson (2005).

The transformation of high abilities into excellence, i.e., exceptional performance and high level expertise, is taken into account by dynamic models such as the Differentiated Model of Giftedness and Talent (DMGT, Gagné, 2002, 2005) or the Munich Dynamic Ability-Achievement Model (MDAAM, Heller, Perleth & Lim, 2005), which distinguishes several stages of achievement of excellence related to the main phases of personal development from pre-school, school, university to professional levels. These models build a bridge to models accounting for the development of professional expertise (Schneider, 2002).

The key function of creativity in the process of talent development is reflected, e.g., by the componential model of creativity developed by Cropley & Urban (2002). Cropley and Urban also provide an extended phase model for creativity and provide guidelines for teachers on how to foster creativity in the classroom by methods such as 'open learning.'

Renzulli's Schoolwide Enrichment Model (SEM, Renzulli and Reis, 2002) provides a practical basis for school programs to identify and foster school children with exceptional abilities and help young people develop their respective talents. An essential tool within the SEM is the Revolving Door Identification Model comprising three types of subsequent enrichment activities of increasing complexity and demands:

- Type I enrichment offers students a wide range of experience and activities in order to introduce them to a variety of topics. It moves students beyond the regular curriculum to potentially exciting new areas of interest.
- Type II enrichment is designed to give students the skills necessary to carry out investigations and develop a range of thinking and feeling processes. It 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), i.e., it represents the type of enrichment most suitable for gifted and talented students. 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. Renzulli and Reis (2002) emphasize that students should emulate professional investigators and select appropriate audiences for their final products.

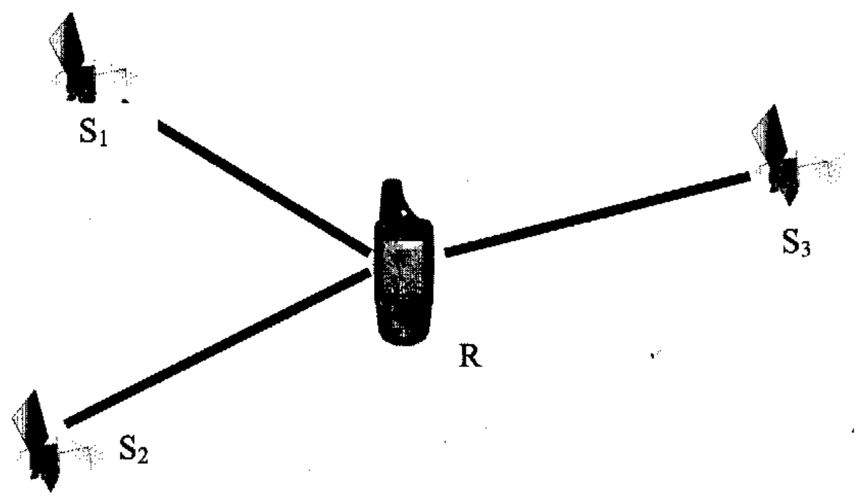
Teachers play a key role in gifted education; their characteristics and necessary competencies have been summarised by Seeley (1985): In type III enrichment the teacher's role changes from that of an educational instructor to that of a mentor, supervisor, initiator, coach, consultant, assessor of achievements.

As described in the remainder of this paper, satellite navigation is a technological subject suitable for a type III enrichment project. It has high application relevance, extreme complexity of the scientific areas involved, and, at the same time, is not likely to be included in customary school curricula and teacher training.

Satellite navigation—Scientific background and project issues

Satellite navigation

The principles of determining one's location by means of satellites corresponds to the methods of terrestrial navigation: If the distances between an unknown location L and three defined locations S_1, S_2, and S_3 are known, the coordinates of L can be exactly calculated. In satellite navigation, e.g., with the Global Positioning System GPS, the location R of a GPS receiver is calculated from its distances to three satellites S_1, S_2, and S_3.



The velocity of light is a physical constant (approximately 300,000 kilometers per second); therefore the distance between the GPS receiver and the satellite can be calculated by measuring the time interval a signal takes to travel from the satellite to the receiver.

Due to the extremely high speed of light (for a GPS satellite which is typically about 20,000 km distant, the travel time is less than one tenth of a second), it is essential to measure the time interval with the utmost accuracy. The satellites are, therefore, equipped with atomic clocks having a time error of less than one second in three million years. Since the distance between the GPS satellite and the GPS receiver requires independent measurements of time at different locations, the clocks on the satellites and the receiver's clocks must be synchronized.

The influence of Einstein's theories of relativity on GPS satellites

According to Einstein's special theory of relativity, a clock ticks slightly slower if it is in motion. Correspondingly, the atomic clocks on GPS satellites (which move at a speed of about 4 km per second) are slightly slowed down by this effect. According to the general theory of relativity, clocks are slowed down by gravitation. Since a clock on a satellite is less affected by the earth's gravitation than a clock on its surface, it ticks slightly faster than a clock on the earth. In satellites both effects are cumulative. However, since the gravitational effect is about ten times larger than the velocity effect, the clocks on GPS satellites are ticking too fast.

Clock changes and project issues

As mentioned above, the clocks on the satellites and the receiver clock have to be synchronised. Consequently, the clocks on each of the GPS satellites are slightly slowed down, in fact by the tiny amount of 45 billionths of a percent. Nevertheless, a satellite navigation system could not work without this tiny clock adjustment.

The inevitable slowing down of GPS satellite clocks gives rise to major questions:

1. How can this change of clocks be calculated?
2. What would happen if the clocks on GPS satellites were left unchanged?
3. What would be the net error of a GPS receiver in this case?

It is obvious that these questions can be used as the starting point for the Einstein GPS project: On the one hand, any bright student working with a GPS receiver and trying to understand the way it works is apt to be interested in this problem. On the other hand, the regular physics curriculum doesn't provide the tools required to attack these questions quantitatively.

The Einstein-GPS Project

The general outline of the Einstein GPS project is straightforward:

1. Provide the necessary tools to the students
    - Introduce the respective subjects at school
    - Let students work with GPS receivers
    - Bring them in touch with the scientific and technological background of satellite navigation

2. Let them work on the subject to develop an approach to solving the problems which arise.
3. Provide a forum for them to present the results of their work

As described in the following sections, this project idea has been realized in close cooperation between the DLR_School_Lab Oberpfaffenhofen and the CJD Christophorusschule Königswinter.

The DLR_School_Lab Oberpfaffenhofen and its Satellite Navigation Experiment

The DLR_School_Lab Oberpfaffenhofen (n.d.) was established in 2003. Its main objective is to attract young students to science and technology. For this purpose, each DLR institute has designed experiments based on its respective core research areas suitable for secondary school students (age 14 to 18). All together, the School_Lab offers a total of 12 experiments provided by eight DLR institutes in Oberpfaffenhofen. The scientific concept behind each of the experiments includes the involvement of scientific and technical experts, a combination of specialist know-how and high-tech equipment (hardware and software), continuous updating and further development of the experiments, and close relation to state-of-the-art research. The satellite navigation experiment is one of these 12 experiments; it was designed by the DLR Institute of Communication and Navigation.

The didactic concept for each experiment is based on small experimental groups (four students and one supervisor), emphasizing autonomous and haptical work, in a time frame of at least two hours per experiment. This corresponds to the concept of open-learning as proposed by Cropley and Urban (2002), allowing the level of complexity to be adjusted to each individual group, with the results depending on the students' ages and capabilities,

In its regular operation the experiments are open to secondary level school classes with up to 30 students. To date, more than 4,000 students have conducted School_Lab experiments.

One of the School_Lab's key activities beyond its regular operation are projects for highly talented students. The DLR_School_Lab Oberpfaffenhofen was involved in many activities during the Physics Year 2005, especially with respect to the subject 'Einstein and Satellite Navigation,' including special students courses (at DLR and other locations), publications such as Hausamann & Furthner (2006), participation in several events and exhibitions, teacher education courses, and, as a highlight, the Einstein GPS project for highly talented students.

School Work at the CJD Christophorusschule Königswinter

The gifted education concept of the CJD Christophorusschule Königswinter 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 Einstein GPS project in the 3rd trimester.

In the first phase, course participants were introduced to Einstein's theories of relativity on the one hand, and to the subject of 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
- economic and technological requirements for satellite navigation systems.

They subsequently produced a corresponding report and presented the results to the class. These individual activities were supported by the teacher, who provided literature on relevant subjects such as the Navigation Brochure (Deutsches Zentrum für Luft- und Raumfahrt, 2002) as well as videos and films which visualised and explained Einstein's theories of relativity. Furthermore, the students were introduced to work with GPS receivers.

Experiments and Scientific Impact at the DLR_School_Lab

The second phase of the project was a three-day excursion to the DLR_School_Lab Oberpfaffenhofen in early November 2005, which represented a further type II enrichment activity:

1. The group was introduced to the DLR_School_Lab.
2. Each student performed the satellite navigation experiment, slightly modified and expanded in comparison to the normal procedure.
3. In a special presentation by a navigation specialist, satellite navigation technology was explained in depth.
4. The issues of time measurement and Einstein's theories of relativity and their importance for navigation were explained in another special presentation (Hausamann & Furthner, 2005).
5. In a visit to the 'Precise Time Facility' of the Institute of Communication and Navigation—a laboratory which provides international time standards and operates several state-of-the-art atomic clocks—students received an impression of DLR's expertise and research in this field.
6. Finally there was plenty of time to discuss the respective subjects, ask questions, raise issues, and define the further steps of the project.

Students' Work to Solve the Problems

After returning home from Oberpfaffenhofen, four of the 11 students began the final (type III) stage of the project. According to the impression of all supervisors, these four students represented the top group of the physics course. They took responsibility for quantitatively investigating the problem, putting everything together, and coming up with answers to the key questions. Since the date of the forum for the final presentation was already set for early December, the group had less than one month to complete its ambitious goals.

Results and Presentation

The 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 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: Several well-known scientists highlighted Einstein's enormous influence on nearly every area of physics and technology. Student groups from all over Germany were given the opportunity not only to listen to these presentations, but also to present the results of their respective Einstein projects. The presentation of the group from Königswinter was well appreciated by the audience, and published on a Web site, from where it can still be downloaded (http://www.schola-21.de/d2/web.asp?PID=1014 ⇒ Die AG's ⇒ Workshops ⇒ Einstein und GPS; in German).

Guidelines for Teachers

Any project with similar complexity requires students with outstanding abilities in physics and mathematics. Further requirements are high creativity and motivation, task commitment, self-confidence, and abilities of self-directed learning and self-evaluation. Schools and classes focusing on highly gifted students such as those at CJD Christophorusschule Königswinter provide, therefore, an ideal basis for finding students suitable for such a project.

Einstein GPS Project Specific Guidelines

The project described in this paper is recommended for other groups of excellent students; the final results of the respective projects could, however, be completely different from those described above. The following advice is intended to facilitate the preparation and organization:

1. A project structure as described above is strongly recommended, especially if the composition of the final group of students is not clear in the beginning.
2. The overall time required for this project is several months, at least two of which should be available for regular lessons in the input phase.
3. To help the students gain practical experience and for didactic purposes (e.g., to explain the methodology of clock synchronisation) at least three GPS receivers should be available.
4. The documentation 'Schulinformation Raumfahrt Navigation' (Deutsches Zentrum für Luft- und Raumfahrt, 2005) incorporates the long-term experi-

ence from the DLR_School_Lab's satellite navigation experiment; furthermore, both authors were members of the advisory committee. It is extremely helpful for introducing the subject of navigation, since it includes a student's workbook as well as background information for teachers and a set of tests with varying complexity (including solutions). An English version of this document should be available in the near future.
5. In European countries in which Einstein's theories of relativity are not incorporated in the standard curricula (e.g., in most German states), it is the teacher's task to introduce this complex subject. However, much didactic material is available through the Internet and from university physics courses.
6. Support from navigation research institutes is vital. In the near future the upcoming European satellite navigation system GALILEO will lead to many research related activities and experimental centers.
7. Another key issue is the possibility to visit an experimental facility enabling the students to conduct their own research—such as the DLR_School_Lab Oberpfaffenhofen.

General Guidelines for Science-related Type III Enrichment

Many projects in other subjects and areas are thinkable; the major requirements for any comparable type III enrichment project are, however, a thrilling subject and clearly defined project goals. Further important aspects:

1. A key prerequisite is a group of excellent students with high cognitive abilities, creativeness, and task-commitment, as well as the necessary qualifications with respect to self-organisation and self-evaluation.
2. The project should be related to one of the teacher's personal fields of interest. Personal expertise and the availability of background material facilitate the task of managing such a project (cf. Seeley, 1985).
3. Close contacts to external research organizations and science labs is essential to guarantee their involvement in and support of such a project.

Another typical example is the 'Geophysics' project currently being carried out in cooperation between the DLR_School_Lab Oberpfaffenhofen and a Hector-Seminar group (10 students, $10^{th}/11^{th}$ grades) in southern Germany (Heller, 2006). The project goal is to detect long-term changes in the students' home areas from satellite images. The scientific expertise and satellite images are provided by the DLR's German Remote Sensing Data Center.

Conclusion

According to all persons involved (students, teachers, and scientist) the overall assessment of the Einstein GPS project was extremely positive; by now another group has formed at the CJD Christophorusschule Königswinter intending to launch a similar project. In the meantime the four students have finished school and are beginning university-level studies in physics, chemistry, and information technology. They have confirmed that their choice of study courses has strongly been influenced by their involvement in the Einstein GPS project.

It can be concluded that enrichment type III projects are perfectly suited to guide excellent students from high school to the doorsteps of university, by providing exciting subjects and thrilling problems, by establishing contacts to the research community, and by supporting the development of key qualifications of personal self-management, thus preparing them for a successful professional carreer.

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