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Expanding STEM Education in Secondary Schools: An Innovative Geography-Physics Course Focusing on Remote Sensing

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Abstract

A new elective school subject called 'Geography-Physics' was developed by the Universities of Bonn and Bochum in cooperation with a German high school. With a focus on remote sensing, the modules of this STEM subject convey information, and present methodology and applications. There are two main sections: the physics of remote sensing, including both mathematics and computer science, and the geographic applications. GIS is a major part of the exploitation of Earth Observation data, but the use of GIS and EO data is not feasible in school lessons due to financial and time constraints. Instead, small specialized GIS tools with embedded EO imagery are used. The tools were developed by two projects, FIS and Columbus Eye/KEPLER ISS, and evaluation and meetings with experts were conducted in close cooperation with the partner school. The first 2-year course of the new subject was completed in summer 2018. The teachers implementing the course have since re-evaluated their concept and revised the syllabus to enhance applicability in professional contexts, to reduce redundancies with other subjects, and to ensure that the overall content fits into the allotted number of teaching hours. The pupils also evaluated the materials and the subject.

Keywords:

education, remote sensing, learning environments, ISS, e-learning

1 Introduction

Germany is facing an increasing shortage of STEM professionals in all areas and at all education levels. In October 2018, there were 337,900 more job vacancies than available qualified personnel (German Economic Institute, 2018). The figures include a shortage of STEM teachers in most German schools. Other contributing causes are: pupils' lack of motivation, which has a major influence on their study and training choices; frequently inadequate school IT infrastructure, although IT skills are crucial for modern scientific and technical work; the fact that development of appropriate teaching concepts which would be

beneficial to pupils is not yet complete. Schools compensate with optional classes and extracurricular participation in STEM competitions (German Economic Institute, 2018).

The Gymnasium Siegburg Alleestraße (GSA, a Gymnasium being an academically oriented secondary school) was awarded the title of 'STEM-friendly school' in 2018, thanks among other things to its introduction of the new STEM subject 'Geography-Physics' in 2015 and its cooperation with Bonn and Bochum universities, where the projects FIS (Fernerkundung in Schulen [Remote Sensing in Schools]) and KEPLER ISS (formerly Columbus Eye, CE) use satellite- and ISS-borne remote sensing and earth observation (EO) data relevant to all STEM subjects. These projects use analogue and digital learning materials that are designed to run on older school computers or pupils' smartphones. The main goal of the cooperation is closer exchanges between educational applications and university research that yield benefits for the projects, the school and especially the pupils. By using real data and image processing techniques, the lessons incorporate recent scientific findings and introduce the pupils to scientific processes.

2 Education portals on Remote Sensing

The FIS and KEPLER ISS projects provide extensive digital and analogue learning materials featuring remote sensing data and methods on their websites fis.rub.de and columbuseye.rub.de. The materials are interactive, interdisciplinary and intermedial, and apply a scientific-preparatory, medium-constructivist approach (Goetzke et al., 2013, Ortwein et al. 2017).

The FIS portal covers 12 topics in geography, 4 in biology, 3 in physics, 2 in mathematics, and 1 in computer science. Furthermore, research tools such as an encyclopaedia, an image gallery, and an interactive learning module about satellite systems can be accessed. Analysis tools with embedded EO imagery include a MeteoViewer, NDVI and image difference calculators, and an RGB classifier. Recently, some teaching units have been revised and updated to include data gained through the Copernicus programme and the Sentinel missions (Lindner et al., 2018).

The KEPLER ISS/CE portal offers 5 topics in geography, 3 in physics, the ISS live stream, and an archive of ISS videos, some of which have been enhanced and annotated. All materials come with tasks and information for pupils along with sample solutions and background information for teachers. The topics are selected from the curricula of the German Federal States, but since these are highly diverse, not all learning modules can be applied in all Federal States. Recently, augmented reality (AR) applications that merge regular worksheets with virtual data from satellites and ISS sensors have been implemented.

The new elective subject Geography-Physics at GSA uses a selection of modules and supporting materials from both sites, thus implementing Remote Sensing as a subject in terms both of theory and of its applications.

3 The Geography-Physics syllabus

The subject is currently taught in years 8 and 9 (ages 13–15), as an elective subject. The pupils have 3 hours of classes per week, which is more than they receive in physics (2h/week) or in geography in year 7 (2h/week; geography is not taught in years 8 and 9). The subject expands on the current state curricula for Geography and Physics as individual subjects (MNSFE NRW, 2007, MNSFE NRW, 2008). The syllabus was developed by the geography and physics teachers, who each teach one semester per year of Geography-Physics.

Most lessons are taught on computers, which is necessary for most of the learning modules. All semesters (4 in total) feature a visit to the class by an expert, and an excursion accompanied by an expert. These experts are the projects' scientists, who create the learning materials and have a background in geography and remote sensing. They provide an extended overview of recent research activities relevant to the topics covered in Geography-Physics and answer questions that might go beyond the teachers' knowledge, delving, for example, into astronomy, ESA and NASA missions, programming and work life. Further training sessions for teachers are conducted regularly.

3.1 Semester 8.1

This semester focuses on physical geography. Since geography in the regular syllabus is strongly focused on socio-economic topics and considered part of humanities education (MNSFE NRW, 2007), the elective subject starts with an overview of the wide variety of subject areas within geography and their methods. Among these is remote sensing, which is covered by the FIS materials.

Table 1: Syllabus for Semester 8.1 – Physical Geography

Topic	Modules	Module content
Research Areas in Geography and Geographic Methods	*No FIS or CE modules available for this topic.*	
Uses of Remote Sensing	FIS: analysis tool and encyclopaedia	Methods, application examples, electromagnetic radiation, sensors, types of resolution, image processing, analysis, classification, change detection.
How to create maps from satellite images	FIS: From Satellite Images to Maps	Classification of satellite images using red, green, blue channels.
Geology basics and remote sensing applications of	CE: Archive videos	Various videos including volcanoes, in Kamtchatka, Guatemala, Sicily, Java, …

endogenic processes	FIS: Tsunami – when waves change everything	Classification of satellite images of Sumatra-Andaman tsunami by colour values. Discussion of earthquakes and tsunami generation. Effects on livelihoods.
	Volcano Excursion	Recent advances and local findings in volcano monitoring. Interferometry.

3.2 Semester 8.2

The focus of this semester is on the physics basics of remote sensing. Since there are regular physics lessons in Year 8, the elective subject needs to avoid redundancies and expand theoretical knowledge with applications and methodology, or to include topics outside the regular syllabus.

Table 2: Syllabus for Semester 8.2 – Physics

Topic	Modules	Module content
Electromagnetic Spectrum	FIS: Encyclopedia	Composition of light and colours, radiation interaction, active and passive remote sensing.
	FIS: Tracing the Invisible	Composition of light, infrared, digital experiment on reflection and absorption. Discussion of implications. Digital experiment on false-colour images.
	CE: Atmospheric Scattering	Rayleigh and Mie scattering in earth's atmosphere. ISS video with and without atmospheric correction.
Remote Sensing Sensors	FIS: Encyclopaedia	Colour detection in Charge-Coupled Devices (CCD) vs. the human eye.
Satellite Orbits	FIS: Research tools: Satellite systems	Satellite orbits: benefits, drawbacks.
	CE: ISS	–"–
	Geocaching excursion	GPS and orbits.

3.3 Semester 9.1

Semester 1 of Year 9 again focuses on physics.

Table 3: Syllabus for Semester 9.1 – Physics

Topic	Modules	Module content
Digital Image processing	FIS: Contrast	Digital Experiment: raster resolution, radiometric resolution, image calculation, histogram stretch, image file formats, point vs. vector data, etc.
Thermodynamics	FIS: Summer in the City	High-resolution thermal images of Berlin in a heatwave; determine heat absorption in different surfaces; apply to everyday problems.
Atmospheric composition	FIS: Research Tools	Composition and stratification of the atmosphere; earth's energy budget.
Radiation budget	*No FIS or CE modules available for this topic.*	
Astrophysics	CE: Earth-Moon system (AR)	Gravitation in the Earth-Moon system; digital experiments on the effect of the Moon on tides.

3.4 Semester 9.2

The final semester of the course focuses on physical geography again.

Table 4: Syllabus for Semester 9.2 – Physical Geography

Topic	Modules	Module content
Weather and Climate	FIS: Analysis tools	Meteorological satellites, weather observation.
	FIS: Atmospheric Circulation	Meteosat 1-day video, cloud patterns, development and relations of cloud and wind systems, convection and advection, global exchange processes.
Exogenic natural disasters	CE: The eye of the Cyclone (AR),	Atmospheric pressure map animations, cross-sections, ISS video. Development and dangers of cyclones.
	FIS: Floods	Dangers of flood to infrastructure; location research using Sentinel-2 true colour, land use map and elevation model for a basic digital flood modelling experiment.
Climate Change	New this year: SNAP tutorial 'Alpine Glaciers'	Introduction to Sentinel Applications Platform, classification of glaciers, vegetation and soil; Change Detection.

The greatest natural disaster, climate change, is discussed in the final part of the course. Now that the pupils know more about physics, measurements and the analysis of atmospheric changes, they can discuss the differences between natural and anthropogenic climate change at a higher level and observe the effects of climate change themselves.

4 Evaluation

4.1 Method

The school is interested to know how pupils react to the new elective subject. The projects' team also need to know reactions to their materials and how to improve them. Thus, the evaluation is performed internally by the subject's teachers with external guidance by the projects' scientists (Schmidt & Perels, 2010). At the very beginning of the course, the pupils' background knowledge is determined, and they fill out a questionnaire at the end of each semester. The assessment is thus summative, but it has formative elements as the content of each semester is adapted in accordance with the results of the previous semester's evaluation. Thus the course content and teaching materials are constantly being improved (Schmidt & Perels, 2010). A partially standardized questionnaire was used because of its high practical relevance and good comparability (Kromley, 2009, Raab-Steiner & Benesch, 2012). Most of the questions are closed and use a rating scale of 1 to 6, which was chosen because of the pupils' familiarity with the German school rating system, which ranges from 1 (very good) to 6 (poor).

4.2 Results

The gender distribution started out with a strong imbalance towards male pupils in 2016. This was reversed in 2017 and has since evened out (see Table 5). Of the pupils who started the course in the years 2016–2018, only 37% had already worked with remote sensing methods. Half of these students were on the 2018 course. However, 58% of those who started the course in 2016–2018 had used satellite imagery at home, usually in the form of Google Maps/Earth or other navigation devices and apps (Lindner et al., 2018). Pupils' expectations included excursions, working with computers (which is rare at GSA), doing practical work applicable to real-life problems, and learning from real scientists about real science and work life.

Table 5: Gender distribution in Geography-Physics

Start Year	Girls	Boys
2016	8	17
2017	10	6
2018	13	10

For the remote-sensing part of the course, the pupils on the 2016–2018 course found the satellite imagery and videos from the ISS quite interesting, and particularly helpful in

understanding the topics at hand (see Figure 1). They felt that their expectations had mostly been met (see Figure 2), which is important for an elective subject.

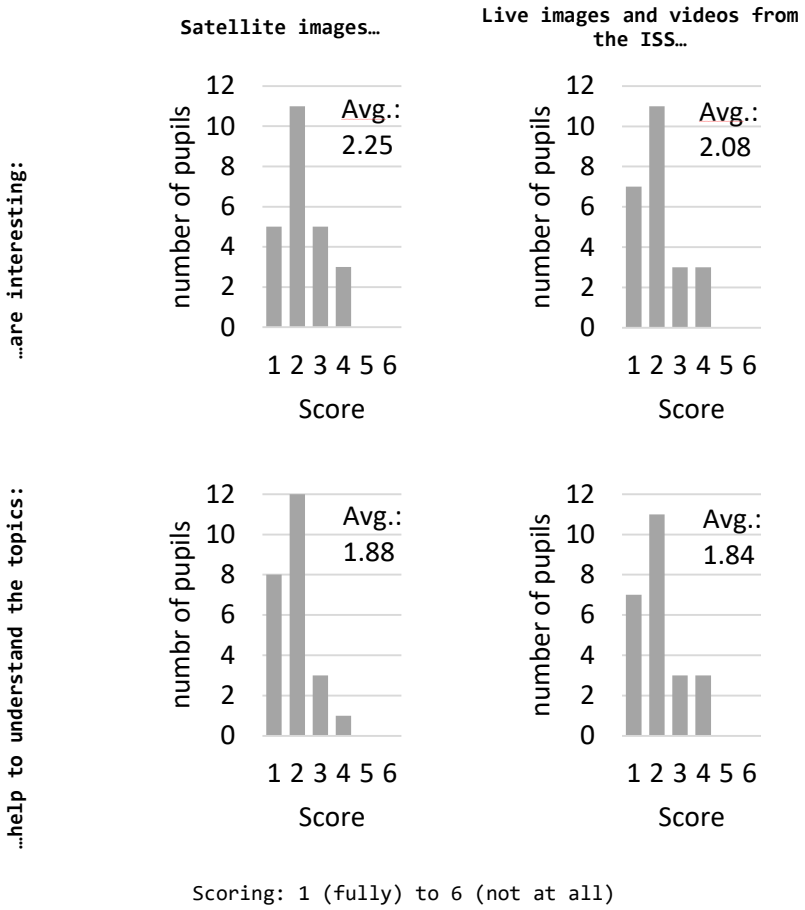

Figure 1: Evaluation of EO materials in school (total no. of pupils: 24, on course finishing in 2018)

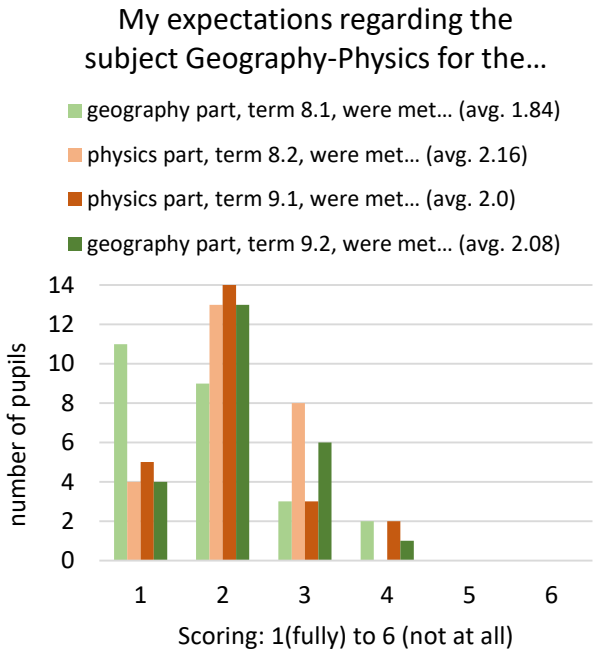

Figure 2: Met expectations of the first Geography-Physics course (total no. of pupils: 24, on course finishing in 2018)

4.3 Discussion

The gender distribution has evened out and gives no indication that pupils are discouraged from taking up the subject due to gender-related issues.

While satellite imagery is already used in everyday life, it is not sufficiently explained in regular classes and it is not much utilized, although pupils consider the images not only interesting but also particularly helpful in understanding complex topics. This indicates the images' usefulness beyond being 'pretty pictures' and suggests significant potential for the extended use of satellite images and quantitative analysis in regular classes.

The pupils accept Geography-Physics well, especially in the first semester. The evaluation of the individual modules shows that the pupils find the content interesting, comprehensible, and applicable (Lindner et al., 2018). This is important for the school to know in order to determine the sustainability of Geography-Physics as an elective subject.

5 Summary and Outlook

The FIS and KEPLER ISS/CE learning modules enrich STEM lessons with topics from physical geography and methodology, especially in remote sensing. They provide free-of-charge, easy-to-use digital experiments for pupils to learn relevant theory and look at

applications in other STEM subjects. The modules also, with little preparation time required, allow teachers to integrate motivating real-world applications with otherwise theory-loaded topics.

The new subject Geography-Physics teaches extensively about STEM, combining the physical and methodological sides of geography with the physics, and consequently mathematics and computer science, necessary for remote sensing. The teachers have defined and revised a syllabus for a two-year course in which they continue to work closely with the scientists creating the learning modules, both to improve the materials and to provide pupils with access to recent research and impressions of real-world applications. The two teachers emphasize the additional educational value of this new interdisciplinary subject. The pupils appreciate the subject for its interesting, comprehensive and applicable content using satellite imagery and ISS videos, the excursions, and its expert inputs.

The pupils' evaluation questionnaire is currently being reworked to understand the long-term effects of the course. Furthermore, the bank of teaching resources of FIS and KEPLER ISS/CE continues to be extended by virtual reality materials and Mini-MOOCs to integrate the bird's eye view of satellites and astronauts in everyday STEM lessons.

Acknowledgements

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