Mineral Resources in Mobile Phones: A Case Study of Boston and Vienna Teachers and Students

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ABSTRACT

As part of an outreach initiative by the Natural History Museum in Vienna, Austria, an interdisciplinary educational module was developed to teach students about sustainability through the lens of mineral resources used to produce mobile phones. The overall goal of the module is to provide teachers of different subjects with a multifaceted tool to include sustainability in their classrooms and create greater awareness of our resource-rich lifestyle. The evaluation of efficacy and impact of the module in formal classroom environments is facilitated through two case studies: an assessment of teacher experiences across Austria with our teaching kit, and an assessment of student learning in Austria and the U.S. During the development of the teaching module in Austria, workshops with 97 teachers were conducted to identify educators' needs and offer an interdisciplinary usable teaching kit. The study showed that teachers greatly appreciated the hands-on workshops and implemented the module in their curriculum. For the student study, 416 students from Vienna, Austria, (209 students) and the Greater Boston area in the U.S. (207 students) were taught the same module by the same instructor. Student performance and learning impact were assessed using pre and post questionnaires. For the Austrian students, an additional long-term post questionnaire was completed six months after the intervention. Students' short-term performances increased significantly immediately after the module. This paper describes the outreach project and our teaching module, and proposes the development of curriculum extensions and teacher professional development for implementing interdisciplinary science concepts. © *2017 National Association of Geoscience Teachers*. [DOI: 10.5408/16-151.1]

Key words: mineral resources in school curricula, interdisciplinary teaching, mobile phones, sustainability

PURPOSE AND LEARNING GOALS

Ensuring environmental sustainability is one of the eight United Nations 2015 Millennium Development Goals (United Nations Development Programme [UNDP], 2000). To achieve this goal, all citizens require a fundamental understanding of science, technology, engineering, and mathematics (STEM) to make environmentally sound decisions, and the STEM education community needs collaboration with competent scientists to develop a scientifically literate society as well as inspire future scientists (American Association for the Advancement of Science [AAAS], 1993; National Science Foundation [NSF], 1996; National Research Council [NRC], 1997).

Today, humanity faces many sustainability challenges ranging from declining mineral resources, and air and land pollution, to water shortages and changing global climate—all directly related to the Earth Sciences (Locke, Libarkin, and Chang, 2012). This especially includes knowledge about soils, water, air, and other resources that need to be handled with sensitivity—thus making Earth Science literacy a key component in the generation of policies that appropriately weigh the importance of resource conservation, use, and sustainability (Feinstein and Kirchgasler, 2015). The Earth Science Literacy Initiative (ESLI; 2010), which is funded by the U.S. National Science Foundation, developed a framework of underlying principles in Earth Science, and identified resources in Big Idea 7: "Humans depend on Earth for resources."

However, young people tend to be unaware of their resource-intensive lifestyle and many seem to feel that their lives are not connected to the environment (Michigan Teacher Expert Program [MiTEP], 2010). Project 2061, an initiative of the American Association for the Advancement of Science (AAAS) has identified several common geoscience misconceptions related to mineral resources as reported by the MiTEP (2010):

- "Diamonds, gold, and silver are valuable, therefore, they are not rocks or minerals."
- "Manmade materials do not come from mineral resources."
- "Earth's resources are not finite—there is an endless supply of water, petroleum, and mineral resources. All we have to do is to explore for them."

When focusing on electronic consumables such as mobile phones and notepads, it furthermore needs to be understood that virtually every good that we use originates from natural resources. Many of these origins are not directly visible and the misconceptions above suggest that students do not make connections between minerals and mining, and the goods they buy. Therefore, we have developed a learning experience to address these misconceptions and used mobile phones as an example device. Ultimately, students need to make the connection between their lives and our Earth in order for them to understand that we are not detached from nature even if it is not visible, such as in consumables, for example.

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TABLE I: Learning goals. In our module, we wanted to provide teachers with an overview of all the different topics related to mineral raw materials and their sustainable usage in everyday life as an appreciation of resources ("geology is everywhere"). The topic can be used to cover many issues and thus, comprises many learning goals in the social sciences (human geography, ethics, and economics) and natural sciences (chemistry, physics, biology, and ecology). Focusing on geoscientific and sustainability issues, some of the main foci are listed here as learning goals, but can differ according to teachers' usage and needs.

Learning Goals
1. Students are able to demonstrate their understanding that mobile phones contain many different materials, especially metals. They are able to name at least seven different metals contained in a mobile phone.
2. Students are able to briefly explain that, for producing metals, ores and rocks need to be mined. Students are able to identify that gold, silver, and aluminum (to name a few) are all metals mined from ores and rocks.
3. Students are able to describe basically that plastics are derived from crude oil.
4. Students are able to briefly explain that natural resources are derived from our Earth and are finite. Students are able to comprehend that we cannot just buy new resources once we have depleted them.
5. Students are able to analyze that, for producing all our goods for now and for the future, we need to conserve these finite resources and treat them sustainably.
6. Students are able to apply critical thinking and explain why mining these materials can encompass ecologic, social, and political issues. They are able to provide different examples for each of the issues.
7. Students are able to explain why processes to manufacture materials from these rocks and ores can be energy consuming and may include toxic chemicals. Consequently, students are able to demonstrate that using fewer resources saves energy and is ecologically responsible.
8. Students are able to explain why recycling is one way to help save new resources from being mined. They can calculate or briefly explain why, for most metals, recycling uses less energy than manufacturing new metals from mined ores.
9. Students are able to demonstrate that using electrical devices as long as possible, reusing and repairing them when possible, and having them professionally recycled once they are nonfunctional is the most sustainable way of using electronics (share, borrow, lease, and repair are some good ways of describing this).

Understanding about resources and environmental protection is also an important concept in geology, combining knowledge about Earth's interacting system processes and integrating elements of chemistry, physics, and biology. Understanding the topic of mineral resources also takes into account social, political, and economic aspects of a globalized world through an increased awareness and understanding of mining and production, and issues accompanied with these processes. Thus, teaching about resources in mobile phones provides a unique opportunity to introduce students to key scientific concepts that integrate knowledge from a diverse range of disciplines and have a meaningful connection to their current lifestyle. Although the topic can be broken down into many facts in a very broad interdisciplinary setting, in Table I we only list the main geoscientific-related learning goals.

Electrical and electronic equipment (EEE) make up a large amount of consumables; in the European Union in 2012, 9.1 million tons of EEE were put on the market. The second largest amount of consumables are information communication technology (ICT) devices, after large household appliances, such as refrigerators, which are much heavier per single device (Eurostat, 2015). Used, end-of-life ICT devices make up a large quantity of waste EEE, but the collection numbers are still not satisfying (Hagelüken, 2010) and stand at a 5%–8% collection rate (Eurostat, 2015). For the U.S., the numbers are similar: in 2011, only 11% of mobile phones were recycled and the rest were trashed (U.S. Environmental Protection Agency [EPA], 2011).

ICT devices include netbooks, laptops, tablets, and mobile phones. We used mobile phones as representative for the vast amount of ICT devices as they provide a useful example: 1.9 billion devices were sold worldwide in 2015 (Gartner, 2016). In Austria, 97% of youth older than 14 years possess their own mobile phone (Edugroup, 2015). In the U.S., these numbers are at 92% for youth older than 14 (Pew Research Center, 2015). With a low recycling rate of 5%–8% and a rapid turnover of every 18–24 months (Gartner, 2016)—many mobile phones are being replaced in spite of still being functional—the need for targeted education concerning this topic clear.

A mobile phone consists of approximately 30% (weight) of different metals, 50% plastics, and 20% glass and ceramics, depending on the device and manufacturing year (United Nations Environment Programme [UNEP], 2008). Mobile phones contain many valuable and rare metals (U.S. Geological Survey [USGS], 2006; Hagelüken, 2010; Organization for Economic Cooperation and Development [OECD], Environment Directorate, 2010). Due to the large quantity of mobile phones sold worldwide, even the comparably small constituency per single device adds up to a significant amount of highly valuable and nonrenewable resources consumed in total. Furthermore, incorrect disposal of mobile phones can release toxic leftovers into the environment and pose potential health risks (Scharnhorst et al., 2007; UNEP, 2008). Thus, mobile phones represent a device common to a modern lifestyle but due to aforementioned issues, cannot be related to an environmentally sustainable lifestyle (Bookhagen et al., 2013).

Understanding the significance of mineral resources as the basis of our society is clearly important, but it is also inherent for a sustainable lifestyle to inspire young people to move "from knowledge to action," which is one of the goals of the federal education ministry in Austria (Austrian Federal Ministry for Education, 2007). In the long term, this means applying scientific content and problem-solving thinking to strive towards being a resource-sensible consumer. This can be correlated to levels 5 and 6 of Blooms' (1956) categories in the cognitive domain (synthesis and evaluation). We hope that our module can give teachers a tool to help them introduce students to important facts and concepts that could potentially promote a resource-sensible mindset.

LITERATURE CONTEXT

The role of education in achieving a more sustainable lifestyle and the focus of environmental education has been described in the late 20th century (Tilbury, 1995) and further expanded upon (Jones, 2010). The project, Interdisciplinary Teaching about Earth for a Sustainable Future (InTeGrate, 2016), a National Science Foundation (NSF) STEP Center grant running from 2012–2016, conducted several workshops and summarized outcomes on their Web site. In this program, strategies include (1) connecting to the world we live in by using real world examples beyond the academic ivory tower, (2) building interdisciplinary connections to integrate different viewpoints, and (3) connecting justice to sustainability by giving an ethical perspective of how sustainability issues affect people in different ways. Sustainability requires systems thinking, synthesis, and contributions from all disciplines—geoscientists, natural and physical scientists, social scientists, and engineers. However, a study of preservice teachers indicated their knowledge base regarding environmental issues was minimal and insight into the social, cultural, and economic complexities was quite superficial (Stir, 2006). Our teachers' feedback from a previous study also indicated that modules implementing geosciences in interdisciplinary teaching were appreciated, as teachers often do not find the time to prepare these lessons or do not feel comfortable enough in making these connections on their own.

In a previous study (Bookhagen et al., 2013), we investigated people's acceptance of mobile phone return programs and concluded that many people lack information about where to return the mobile phones and why there is a need for proper return and recycling. A lack of awareness of the valuable resources in a mobile phone is one barrier, mainly because people do not see the need to recycle the materials in the device, and will therefore not make the effort necessary to do so. Also, people were unaware of the social aspects connected to mining some of the metals and that social and ecological conditions in the mining sector can be complicated. Our inquiry indicated that educational materials implementing a sustainability approach were needed, and that both the social aspects of resource extraction and processing, and the scientific background of the resources used need to be addressed. We felt that a special focus on the geosciences would be ideal to integrate these aspects. Informational material that we collected for our module did not provide enough background information and only implemented either the social or science aspects, but not both (USGS 2006; SWICO, 2009).

We developed a module that combines the mentioned strategies and aspects using inquiry-based teaching and hands-on activities. Also, we adhered to the conceptual framework of the three dimensions suggested by the Next Generation Science Standards (NGSS, 2013) guidelines by following the suggested major practices, crosscutting concepts, and disciplinary core ideas. Our topic specifically covers NGSS' Earth and Space Sciences (ESS) third core idea, Earth and Human Activity, particularly ESS3.A: Natural Resources and ESS3.C: Human Impacts on Earth Systems, in addition to ESS2: Earth's System ESS2.A: Earth Materials and Systems, which should also be covered for general understanding (see also NRC, 2012).

Following Piaget's constructivist learning theory (Piaget, 1967), which states that learners construct knowledge for themselves, students should be encouraged to learn more than just facts and theories in order to effectively understand science (NRC, 1997; National Center for Education Statistics [NCES], 2013). With inquiry-based teaching and hands-on activities in which students formulate and test their own ideas, teachers can help students to gather understanding and knowledge rather than reproducing a series of facts. Constructivism transforms the student from a passive recipient of information to an active participant in the learning process. Both methods have also been shown to facilitate learning complex topics (e.g., Barab and Luehmann, 2003; Breslyn and McGinnis, 2012) that support our multifaceted topic. The United Nations Educational, Scientific, and Cultural Organization (UNESCO, 2010) also encourages teaching and learning for a sustainable future by using inquiry-based teaching in which students carry out an investigation instead of solely attending lectures. Creating understanding through an iterative process, which seizes and reforms prior knowledge (NRC, 1997) and includes relevant current issues, has also been shown to be supportive for the learning process (Ballantyne et al., 2001). We encouraged students to become engaged by applying their existing knowledge and real-world experience to a device they care for and feel connected to. We asked students to hypothesize and test their theories to draw conclusions from their own findings, thus forming their own opinions by using all the facts they gathered.

Teachers who enjoy and are passionate about a topic are more likely to present the lesson in a more engaging and effective way to their students. Subsequently, we focused on a relevant and interesting topic for the teacher as well as the student. As summarized by Breslyn and McGinnis (2012), a lack of planning and instructional time, insufficient materials, and inadequate professional development have frequently been cited in the research literature as barriers to inquiry-based teaching and the implementation of hands-on modules for teachers. Findings from our previous study with teachers (Bookhagen et al., 2014) suggest that ready-to-use lesson plans with hands-on tools in Earth Sciences would be greatly appreciated and could be another way to strengthen the application of Earth Sciences and encourage teaching in school. Thus, we developed this mobile phone module as an educational outreach activity. We also included a brief teacher study in our outreach project, as research on teachers has also been coming into focus (e.g., Remillard et al., 2009).

STUDY POPULATION AND SETTING

The International Council of Museums (ICOM) states the significance of museums as follows: "Museums have an important duty to develop their educational role and attract wider audiences from the community" (ICOM Principle No. 4; ICOM, 2010, p. 13). For Earth Sciences in particular, museums and their school programs play an important role (Ramey-Gassert et al., 1994; Hooper-Greenhill, 2007). The

Natural History Museum in Vienna, Austria (NHM) plays a leading role in the country's geoscientific educational outreach activities in out-of-school learning places. In 2014, it had approximately 2,300 classes using the available activities specifically designed for schools.

Approximately 50,000 students visit the NHM every year (average from 2011–2014) and hear about a wide range of science topics including paleontology, archaeology, biology, and geology. The NHM museum pedagogy has a long history of developing educational modules with exercises and teaching material that provide students with multiple opportunities to explore difficult concepts in natural science and Earth Science. Usually, these modules take place at the museum as part of a class visit. However, not all teachers can bring their classes to the museum, so teachers and schools that are unable to visit due to distance, time, or funding should have access to similar learning experiences without requiring access to the displayed exhibitions. Ready-to-use modules that can be obtained as kits are an important method of expanding accessibility of these topics and learning experiences. Our module development began as an educational outreach part of the museum and continues to be part of the museum work. The module testing in a formal classroom environment was facilitated through two case studies: an assessment of teacher experiences across Austria (Study 1), and an assessment of student learning in Austria and in the Boston area in the U.S. (Study 2).

The teacher study illustrates the usage of this cross-disciplinary topic and premade materials kits in the classroom. The student study shows the possible topics and the need for emphasis. Teachers can choose to focus on a particular topic, depending on their learning goals with regard to teaching about sustainability and natural resources.

Study 1: Teachers in Austria

Teachers were recruited via an email distribution list from the museum that reaches federal school authorities and schools throughout Austria. In the free 3-hr teacher workshops, we introduced the prototype material box in November and December, 2011; each teacher could keep a classroom set of the material box (four boxes) free of charge. Ten months after the teacher workshops, questionnaires were distributed to teachers via email to measure their feedback of the module and their implementation in the classroom.

We conducted 10 professional development teacher workshops across Austria at local schools in each federal district. All 97 teachers came from different public schools. Experience from teachers varied from beginners to proficient, and they came from a wide range of backgrounds, including chemistry, biology, physics, geography, political science, and social science, as well religious education (a partly facultative school subject in Austria) and technical subjects. Instructors were teaching grade 7 and up with students aged 13 and older. Eight teachers also worked in grade 5. Of the teachers, 44 teachers were male and 53 female.

Study 2: Students in the U.S. and Austria

For our student study and material kit assessment, the same teacher taught the same module to students in the U.S. (May 2012, $n = 207$) and Austria (June–July 2012, $n = 269$). All schools for the study were recommended by teachers from a previous study, so we did not know the teachers or students beforehand. All parts of the module were translated from German to English (worksheets, PowerPoint presentation, quiz game). Time controls were only slightly modified when necessary to fit practical needs, such as having 90 min versus 80 min, and two single lectures versus double block lectures (3 out of 10 classes).

Parents submitted a signed consent form granting permission for their child or children to participate in the study, and students signed assent forms acknowledging their participation. Students were made aware that they would not be graded, that the survey would be solely for assessment of our teaching methods, and would be treated confidentially. Students were given sufficient time to complete the questionnaires, which took an average of 7 min.

Students from both countries were from the same age group. In Vienna, 269 students from three schools participated, with 209 students from grades 9, 10, and 11. We also included two classes from grades 7 and 8 (60 students) to test and compare whether the material and subject would be appropriate with younger students. In Boston, 207 students from three schools participated from grades 9, 10, and 11. In the Vienna sample, 57% of the students were female and 43% were male. In the Boston sample, 49% of students were female and 51% were male. All schools in Vienna and Boston were public schools. School type and social standing of test schools were comparable. All settings were chosen to be comparable (time, age group, class size, gender distribution, and social standing).

MATERIALS AND IMPLEMENTATION

In this section, we provide an overview of the module development and kit content as a model for instructors or organizations interested in conceptualizing and developing their own interdisciplinary teaching kits. We also describe a sample 90-min part of the module and provide supplemental teaching material. We then evaluate the efficiency of the module and material kit as curriculum supplements in formal classroom environments.

The teaching kit was developed through an iterative, collaborative process, first involving pilot tests with test students, followed by teacher workshops, during which the lessons were continually revised, as recommended by Briggs et al. (1991). The evaluation of the module was facilitated by examining teacher feedback after teachers from these workshops taught the module ($n = 97$), and by assessing student learning in Austria and the U.S. with test classes ($n = 416$ in grades 9, 10, and 11 and $n = 60$ in grades 7 and 8) that were taught by the authors. The first author is a scientist working in the field of materials in mobile phones, and has also worked with teachers and students for over 10 years.

Over six months during the development of the accompanying kit and lesson plans in spring and summer of 2011, we pilot tested the module with students. This testing included four sample classes with a total of 83 students from the targeted age group (grades 9 and 10). These test lessons with students provided valuable feedback to refine the material box and test hands-on exercises in order to produce a prototype. In November and December, 2011, the following teacher workshops were conducted with

TABLE II: Materials from the kit used to address different topics and their location in a mobile phone. Listed here are the ores that we used for our materials box, their application in mobile phones, and the reason for choosing these materials.

Representative Material	Where in Mobile Phone	Topic Addressed and Reason for Inclusion
Iron (ore: magnetite)	Small screws and bolts	Great for showing a magnetic rock; iron is a common metal, abundant, high connection to industrialization, mining history
Copper (ore: chalcopyrite)	Cables and connectors, sheeted in printed circuit board	Abundant; important metal; diversity of usage; recycling
Gold (gold foil)	Corrosion resistant contacts and thin bondwires	Common and extravagant metal; high environmental impact when mined; ecological and social aspects of small-scale mining; recycling
Aluminum (ore: bauxite)	Thin covers and plates on printed circuit board	Common metal; high environmental impact for processing; good example for energy saving when recycled
Silicon (mineral: quartz; polysilicon in early stage of processing)	Microchips and processors (key component for Integrated Circuits); also glass for display	Abundant mineral; diverse application for plain glass as well as high-tech silicon wafers for microchips
Lithium (ore: lepidolite)	Battery	Important element for future technologies (Li-ion batteries); beautiful mineral; concentrated only in few countries (scarcity)
Tantalum (ore "coltan")	Electronic capacitors and multichip resistor arrays	Tiny amount needed but very important; has been connected to child labor and named as conflict mineral (social conflicts, war in Democratic Republic of Congo)
Oil shale and plastic pellets (early processing state)	Plastics (polymers) in case and as covers, isolators	Importance of crude oil (not suitable for classroom use due to safety and health reasons) as a base for so many applications other than as fuel for cars (e.g., chemicals for medicine, soaps, detergents)
Clay minerals	Isolators, in multilayered capacitors	Seemingly unimpressive yet common in daily life and used in highly sophisticated applications (from coffee mugs to cosmetics to special ceramics)

97 teachers all over Austria using this prototype teaching kit and preliminary worksheets. Following the workshops, direct written and oral feedback was collected from participants. The teacher workshops were designed to give in-depth information and ideas of how broad and interdisciplinary the subject could be taught, in addition to coaching the hands-on exercises that could be conducted with the students in the classroom. After the teacher workshops, the module was adapted to fit teachers' needs. A teacher background workbook was developed with further information, ready-to-use worksheets and solutions, and suggestions for possible instruction methods that were developed iteratively during the workshops together with the teachers. Teachers also received the presentation used for the workshops. The teacher workbook and presentation were mailed to teachers approximately two months after the workshops were conducted in January, 2012. All worksheets, which were to be used as starting point for student discussions, were in MS Word format so teachers could adapt them to their own needs. The workbook is comprised of 101 pages (including worksheets); thus, we only included a few focus topics in this paper. Each teacher received the complete package consisting of the material box, presentation, and workbook. The final material box for conducting the student test classes in Austria and the U.S. remained the same as the prototype version, except for slight modifications to the layout.

The material box contains 11 mineral raw materials used as representative mineral resources to manufacture mobile phones. Eight of these were untreated minerals, rocks, and ores, and three were already processed but early stage of production. For classroom security reasons, we used oil shale instead of pure crude oil and refrained from using lithium salts and used a lithium ore instead. Teachers were asked to always make sure that students keep safety standards in mind: although none of the mentioned raw materials are toxic, students should not eat or lick minerals and always wash their hands after the exercise.

The module describes different phases of the life cycle of a mobile phone with hands-on exercises and discussions linking to mining, production, usage, and the recycling phase. The minerals and rocks in the box were specifically chosen to address different topics in order to also include the social and ecological issues of the life cycle stages (e.g., conflict minerals, child labor, and environmental pollutions in the vicinity of mines), as well as the need for conservation and protection of resources and their recycling.

Table II shows the minerals and ores we chose, where they can be found in a mobile phone, and the reason for including the material with the accompanying topic. Teachers who would like to follow our module can use this table as an answer sheet, or use it to develop their own worksheets for students.

The instructions and safety standard measurements in Supplement 1a (available in the online journal and at http://dx.doi.org/10.5408/16-151s1) should be reviewed before starting with the module. The 90-min module starts with a practical exercise: In small groups of three to five students,

FIGURE 1: Material box. Picture of the mineral resources box in use. In the back, students use the board game to determine the names of the mineral resources.

students disassembled a dysfunctional mobile phone and explored the different components by naming them and discussing possible material content, using a prepared table, and asking for the parts and material of the mobile phone (see Supplement 1b). Depending on knowledge status, online research can already be integrated at this stage, but students were explicitly asked to explore. After discussing students' first thoughts of what they hypothesized to be the material of a mobile phone, they were asked about the origins of the materials and metals they named; during this step, students were guided to the terms ore, commodity, and mineral raw material. In the next step, students were given the mineral resources box (Fig. 1) to discover some representative mineral resources used to manufacture mobile phones. A magnifying glass and magnet are also included in the box to investigate minerals and smaller parts of the mobile phone. The accompanying quiz (see Supplement 1c) for the box is a board game to help students name the mineral resources by physical properties. Students began by placing all minerals on the left side of the game and then continuously followed each question on the top to reach the stage where all minerals lie on the right-hand side next to the name of the material. After identifying all minerals with the quiz, which takes about 5–10 min, laminated cards were used (see Supplement 1d, which is a list of the mineral resources represented in the box, cut into light gray and dark gray cards). We allowed students to use one smartphone per group to support their investigation via online search tools, but the investigation can also be conducted using computers or tablets instead of smartphones. First, students sorted the metals (light gray cards; e.g., copper) to the matching mineral (e.g., chalcopyrite) and placed them next to the mineral on the board game. The next step involved arranging the dark gray cards (list of the components of a mobile phone cut into cards) to the corresponding mineral or raw material. To conclude, students found the matching component of the disassembled mobile phone and placed it next to the series. Thus, each mineral was matched with one light gray and one dark gray card and the connection from mineral resource to metal/commodity and mobile phone component was established. The exercise can also be accompanied by handing out a periodic table of the elements and having students mark all elements they hypothesize to be part of a mobile phone. See Supplement 2 (available in the online journal and at http://dx.doi.org/10.5408/16-151s2) for the list of elements that can be part of a mobile phone.

Additional exercises for main production countries and social and ecological issues of each commodity are another central point that can be included in this lesson or in the following lessons (the workbook provides premade worksheets for online research, group work, and station learning with students' presentations). Due to time restrictions, in our case study with students we discussed the topics of each commodity via a presentation during which we provided much of this information. Students discussed how many mobile phones they have at home, where they should bring them when they are not needed anymore, and why correct recycling is the most sustainable way of treating broken mobile phones.

The box and the ready-to-use lesson plan for teachers with teaching methods have been available at the Natural History Museum in Vienna for purchase. Also, since the teacher workshops are not available anymore, teachers could choose to organize a class trip and conduct the module in the museum, taught by our trained staff. In Austria, 2,100 boxes were ordered between 2011 and 2015. The material kit also became part of the Raw Materials Expedition by the German Ministry of Education and Research (BMBF) in the Year of Science 2012 (German Ministry of Education and Research, 2012), and 2,000 boxes were sent out to schools, museums, and other educational institutes throughout Germany. Both projects are now finished, and so far, no further funding has been acquired to produce new boxes.

EVALUATION

Overall Design and Strategy

The teacher feedback study (Study 1) investigated the practicability and functionality of the created module and the material kit in a classroom environment, as well as the usage of different accompanying materials, including premade worksheets and a ready-to-use presentation. We also wanted to explore whether there was need for teacher development workshops for using the material kits.

Student learning (Study 2) was reflected to examine our module for effectiveness. We also wanted to compare students' pre knowledge and perception of the subject in the U.S. and Austria to gain a first impression of whether these two educational settings differ significantly. All findings were used to further adapt the module for classroom usage and not for addressing a formal research question.

Methods

We utilized mostly quantitative datasets for the evaluation of both studies. For systematic comparison of large numbers, quantitative research is a reliable method (Creswell, 2002; Punch, 1998). Here, we merely wanted to test students' knowledge gain and compare the results. We also included qualitative questions for a deeper understanding of contexts; since the topic covers a large range of aspects, we wanted to inspect which issues involved students the most. The qualitative answers from the questionnaires are only

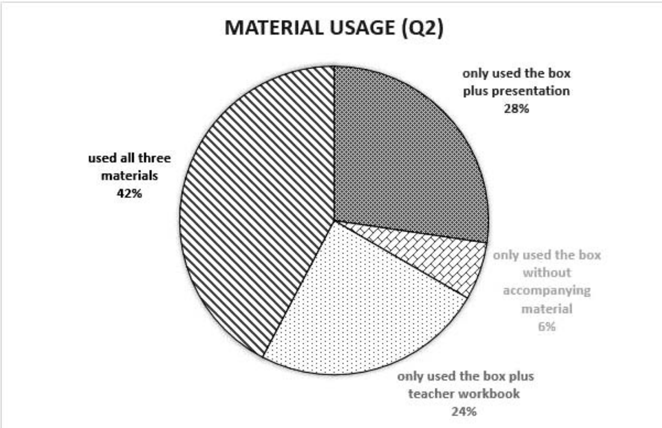

FIGURE 2: Usage of the provided material types. Teacher feedback (n = 34) to question 2 (information about materials usage) from teachers who participated in the professional development workshops in Austria.

briefly summarized below. Please see Supplement 3a (available in the online journal and at http://dx.doi.org/10.5408/16-151s3) for teacher questionnaires and Supplement 3b for student questionnaires. We used both datasets to obtain different insights.

Of the 97 participating teachers from the workshops, 34 returned their feedback questionnaire (37%) via email within 10 months after the teacher workshop. The chance of anonymous reply via postal mail was also given. Teacher feedback was transferred into an Excel spreadsheet. All questions were Yes/No questions and coded accordingly (Yes = 1, No = 0). Additional qualitative explanations to the answers were also collected.

The student surveys were administered at three stages: (1) immediately prior to science kit instruction (pretest, N = 476), (2) immediately after science kit instruction (posttest 1, n = 476), and (3) approximately 6 mo after science kit instruction (posttest 2, Austria only, n = 200). For practical reasons, posttest 2 (long-term posttest) was only feasible for participating students from Austria. The long-term posttest from two test classes, then grade 7 and 8 in Austria, could not be obtained and were omitted from further consideration. Pretest and posttest 1 were printed on the same sheet (front and back side) to ensure paired testing.

In order to preserve anonymity, the Austrian long-term posttests were not arranged to corresponding students but had to be analyzed blindly. Ten students were missing from classes. At each stage, the identical survey was administered. The long-term posttest for Austria had two additional qualitative questions. We calculated scores for Vienna students from grades 9, 10, and 11 (n = 209) grade versus grades 7 and 8 (n = 60) separately to better compare with the 9th, 10th, and 11th grade Boston students (n = 207). Student questionnaires were transferred into an Excel spreadsheet. Open-ended responses/qualitative data were sorted by similar thematic answer (questions 4–9) and used as information for how well students understood the topic.

For student question 1 (which raw materials can be found in a mobile phone?), multiple answers were possible. Incorrect answers include uranium, coal, radioactive rays, and no answer at all. If students listed one incorrect answer even along with a correct answer, we counted the entire question as incorrect. For correct answers, almost all metals from the periodic table can be accounted for in a mobile phone (see Supplement 2). Since we stated the question purposely as "raw materials," oil (to produce plastics) and broad terms such as metals were also allowed and counted as correct. For questions 1–3, responses were coded as 0 = incorrect, 1 = correct.

Paired t tests were used to compare two population means that are correlated (pre- and posttest of the same person). We determined the p-value, which indicates the probability of the mean difference occurring by chance. We also calculated the effect size using Cohen's d, which is the magnitude of the difference between groups (Cohen, 1990; Coe, 2002; Sullivan and Feinn, 2012). Statistics for p-values were calculated using GraphPad, an online statistics tool.

RESULTS

Study 1

Almost all responding teachers (91%) stated the material was relevant for their curricula. Comments included the relevance and actuality of the topic, the interdisciplinary teaching opportunity, and that the whole package (material box, presentation, and workbook with premade worksheets) fit together well for individual classroom use.

Fig. 2 shows the usage and different ways of using the materials. Most teachers used all the provided materials (box, teacher workbook, and ready-to-use presentation). Table III summarizes information regarding school subject, class level or grade, and thematic implementation of the material.

All respondents stated that disassembling a mobile phone alone would not have been sufficient and that the material box is a useful haptic tool. Comments included that actually holding raw materials (rocks) in their hands amazed most students and, according to teachers, helped make the connection between origin and application.

Teachers perceived the teacher workshop as helpful, stating it efficiently showed the direct usage of the material and gave background information about the interdisciplinary topics that could be covered. Some respondents stated that it worked very well by getting them interested in the topic and prompted them to further explore the topic.

Twenty teachers would have used the materials without the workshop, but 11 of them said that they would have used the materials, but they wouldn't have been as confident, or would have needed a lot of preparation and would not have been able to find the time to prepare. Thirteen teachers stated they would not have or probably would not have used it due to time restraints for preparation, and four said they would not have used it at all. Eleven teachers specified that the workshop provided opportunities to question scientists knowledgeable about the subject, and that the workshop inspired many ideas and possibilities about how to use the materials in an interdisciplinary investigation, which a mere self-study on the topic probably would not have covered.

Study 2

All teachers of the students' classes reported that they had not covered the topic prior to our intervention. Thus, we believe that students started on the same comparable level and the pretest can be used as a starting point to compare

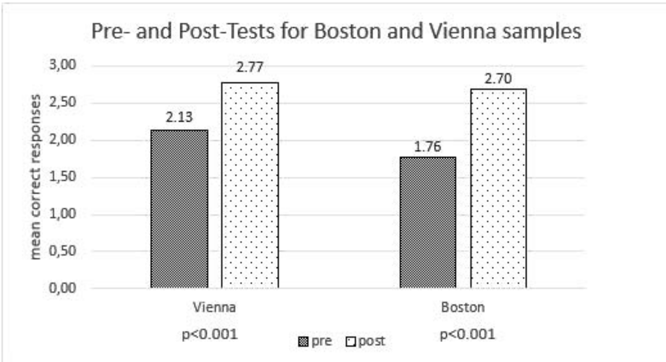

FIGURE 3: Average of pre- and posttest sum scores from Vienna and Boston. Students' performance shows a significant increase from pretest to posttest for both Vienna and Boston with p below 0.001, and a very large effect size with Cohen's d above 0.8.

knowledge gain from our intervention (I-TECH, 2008). To strengthen this, we also assessed results of the two test classes from grades 7 and 8 in Austria (N = 60), which mainly showed the same results in knowledge gain and were merely used to test whether the module can be used for younger students. These test results are not specifically included in this paper.

Supplement 4 (available in the online journal and at http://dx.doi.org/10.5408/16-151s4) shows the results of the 10 most named terms in question 1. Supplement 5 (available in the online journal and at http://dx.doi.org/10.5408/16-151s5) summarizes the correct answers for Vienna and Boston for all questions 1–3 and the test phases. Question 3 (What is plastic made up of?) was the question answered incorrectly most frequently in both the Austrias and U.S. groups in the pretest.

Figure 3 shows the average of pre- and posttest sum scores for the three quantitative questions. From an achievable sum score of 3 (scoring all of the three questions correctly), students in Vienna scored 2.13 on average in the pretest and increased to 2.77 at posttest. Boston students started with an average score of 1.76 and increased to 2.7 at posttest. Using a paired t-test, students' performance shows a significant increase from pretest to posttest for both areas with p below 0.001, and with a Cohen's d above 0.8, showing a very large effect size. The paired sample t test results for Vienna is $t(203) = -12.00$, $p < 0.001$, Cohen's $d = -0.98$, and for Boston is $t(202) = -15.83$, $p < 0.001$, Cohen's $d = -1.29$.

Generally, students in Austria performed slightly better before instruction than students in the U.S. Students' performance in the U.S. was still a little below that of students in Austria in the posttest after the instruction.

Long-Term Posttest (Austrian Students Only):

All three test phases of Viennese students are summarized as a graph by mean correct answers in Figure 4. Vienna students started with an average of 2.13 correct answers in the pretest and rose to 2.77 in the posttests (paired t-testing possible due to matched pre- and posttests, ($p < 0.001$). Six months later, the same students' answers dropped to a 2.67 average. Overall, the knowledge gain from pre- to long-term posttest is statistically significant (independent t-test, $t(200) = -8.05$, $p < 0.001$, no paired t-testing was possible due to anonymity). The knowledge loss from posttest to long-term posttest is not significant, $t(200) = 2.09$, $p = 0.034$). The effect size (Cohen's d) for Vienna pretest and long-term posttest shows a large effect with -0.81. The effect size for Vienna posttest and long-term posttest is 0.21, which is a small effect. Altogether, the knowledge gain from pre- to long-term posttest is clearly visible and shows a large effect size.

TABLE III: Implementation of the module by teachers. Austrian teacher feedback ($n = 34$) to question 3 (information about implementation of the module). Multiple answers were possible.

Item	%
School subject	
Chemistry	53
Biology/environmental sciences	50
Physics	32
Geography	18
Other	9
Class level	
Grade 8	56
Grade 9	47
Grade 7	38
Grade 10	38
Grade 11	15
Grade 6	12
Grade 5	9
Grade 12	6
Topics addressed	
Recycling and recovery	71
Mineral resources and commodities	65
Ecological and social issues related to mining	35
Chemistry of the elements	32
Scarcity of resources	18
Geology	15
Rare Earth metals	15
Class project	12
Ecology	9
Mineral resources of Austria	6
Semiconductor technology	3

Qualitative Segments: Questions 4–9 for Students and Feedback Sections for Teachers and Students

Students' answers for why mobile phones should be recycled showed all aspects in different foci: U.S. students mostly pointed to reusing resources (49%), taking care of toxic contents (31%), preserving the environment (20%), and saving valuable metals (20%). Austrian students mainly named reusing resources (35%), toxicity (24%), and saving resources (22%). When asked why they should not leave a mobile phone unused in a drawer, the most frequent

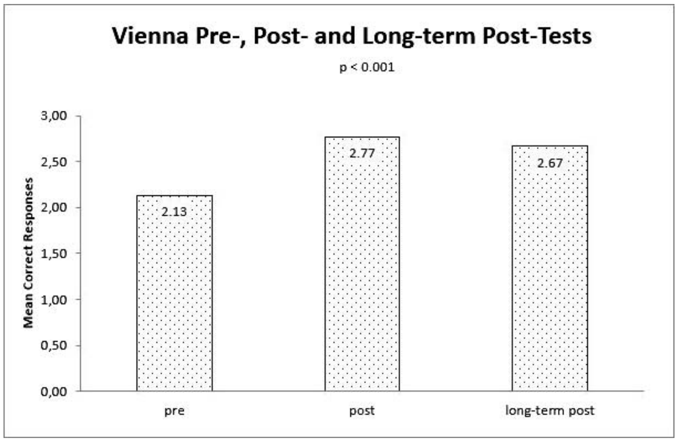

FIGURE 4: Vienna students test scores for all test phases, summarized by mean correct answer. The knowledge gain from pre- to long-term posttest is statistically significant with $p < 0.001$ and shows a large effect size.

response from both U.S. and Austrian students was some form of the "reuse and preservation of resources." U.S. students more often mentioned that some elements were valuable (53%), while more Austrian students stated preserving the environment (48%). In all qualitative posttest questionnaires, when asked what they liked most about the module, most (U.S. 87%; Austria 81%) answered disassembling the mobile phones and handling the rocks/minerals (U.S.: 41%, Austria 36%). Students were able to state as many points as they liked.

Teachers

The interdisciplinary nature of the learning experience was specifically noted. The Austrian teachers stated that they are encouraged to provide interdisciplinary teaching opportunities, but that there are inadequate training opportunities to support such teaching. Teachers described that the provided material was relevant across several science disciplines, supporting the flexibility and applicability of the learning experience. Teachers stated that they and colleagues often avoided teaching mineralogy for lack of education and confidence, but now felt more confident in teaching this module after completing the teacher workshop. Providing them with extensive background information to see the big picture was also praised. Teachers appreciated that they were thus able to choose their own key points suitable for such a complex topic and better fit it into their curricula. Some teachers stated they had never thought the subject (mobile phones) to be this extensive. One teacher stated, "This topic is a bottomless pit and is great for further class projects."

The room for comments was also used to thank us for the workshop and the prepared material, with seven teachers specifically stating they would like to have more prepared materials like this. In the oral feedback during instructions, teachers mentioned that they never thought the simple topic of mobile phones could lead to so many different aspects of and insight into different learning subjects and topics. Nine teachers stated that they liked discussing the topic with other teachers, which also engaged them in thinking about curriculum collaboration with colleagues from their school in order to implement the topic in different subjects.

Last but not least, in almost every workshop teachers noted that they themselves learned a lot about this complex topic and how many concerns are involved when talking about mobile phones. As one teacher stated, "Somehow we all know this but we never really think of it and never really implemented it in school."

Students

Notable students' quotes included "Cool doing something new and different," and "Didn't know rocks could be so cool." The need for recycling and preserving our resources was one of the solutions named to minimize our effects on natural resources, but in the discussion, students also recognized that our consumer lifestyle does have an impact on our Earth. Many students were specifically upset by child labor and health issues connected to mining. Almost a third 32% (U.S.) stated the notion that they didn't know things were so unfair. Students stated they were surprised that geoscience was connected to such a broad range of topics.

INTERPRETATION

Teacher Experience

Our approach was appreciated by geography, chemistry, and physics teachers as a good method to combine interdisciplinary subjects and to bring a sustainability issue into the classroom through a hands-on approach and up-to-date topic that interested many students due to their daily interaction with mobile phones, aspects that are also suggested by the InTeGrate findings. Choosing a geoscientific content that can be clearly connected with other subjects proved to be another advantage to interdisciplinary teaching about sustainability, as suggested by Gosselin et al. (2013).

The teacher workshop assessment strongly supports Foley et al.'s (2013) observations: Teachers were mainly "looking for versatile curriculum supplements, not replacement curricula. They wanted hands-on lessons that related to 'hot' topics that could be incorporated into their existing curriculum and aligned with state standards. They were virtually unanimous in not wanting a prescribed curriculum targeted at a specific grade or subject" (p. 259). Since sustainability teaching is mentioned in curricula of different subjects, our approach is one useful way of connecting teachers of different backgrounds at schools, engaging them in an interdisciplinary topic, and attracting students to the topic as well. However, since science standards in the U.S. and Austria are very different, we could only align them to Austrian standards when developing the module. Teachers from the U.S., however, noted that the material would fit well into their curricula and we have already noted their alignment to NGSS core ideas.

Students' Performance

Assessment of the module by measuring students' performance and by comparing the different countries shows that we have chosen a promising teaching method and topic. The noted actuality of the topic, all-day-related relevance, and hands-on exercises in our methods support other projects' findings (InTeGrate, 2016).

Both the Boston and Vienna samples show a significant increase in performance from pre- to posttest, suggesting that the improvement can be attributed to our module. The scores of the pretest results for questions 1–3 were already relatively high, which may be due to the straightforwardness of the questions. We were also particularly interested in how students' answers would change from pre- to posttest in terms of naming different materials that can be attributed to our intervention (i.e., some of the materials that were not included in students' answers beforehand but showed up in the posttests and thus, can clearly be attributed to our intervention, see Supplement 4). We also wanted to address misconceptions about radiation or rays (that some students attributed to radioactive materials such as uranium) to briefly mention the physical nature of electromagnetic waves. This issue, which has been discussed in the media, concerns possible harmful rays in mobile phones and we wanted to highlight the science behind the issue.

We noticed that younger students (in grades 7 and 8) had problems using the cards and placing them next to the mineral resources, even when using online research. More confident pre-knowledge (e.g., in chemistry) seems to be needed to complete this task.

In general, we did not want to teach only about content, but aimed at creating awareness of the complex topic of limited Earth resources in connection with our consumer lifestyle and encourage curiosity in students about geoscientific content. A quantitative and qualitative questionnaire will not be able to measure this impact, and in-depth student interviews would clearly be more suitable to measure such an impact. However, this was not feasible for our study due to time restrictions, group size, and location logistics in two countries.

Long Term Retention

The long-term posttest (Vienna only) shows that students seem to retain some of the knowledge (e.g., students reported some materials contained in cell phones that were not mentioned before, such as silicon). However, it became apparent that they mostly remembered the part where they actively disassembled the mobile phones. The transfer of knowledge to a deeper understanding of the subject we wanted to evaluate by using the term "sustainability" is difficult to measure. The long-term posttest from Vienna suggests that a single teaching module does not lead to a change in long sustained preconceptions for students (e.g., two students still answered, "we can just buy all the raw materials we need," which is the direct opposite of the intended message of limited resources). This suggests that other strategies need to be considered to improve a deeper retention. The content needs to be taught in different ways and discussed repeatedly to achieve a long-term understanding, as recommended by the NGSS (2013). The issue of consumer lifestyle affecting our Earth does not usually come up in the everyday life of teenage students. Thus, although we started an important discussion with an innovative approach by using an everyday device such as a mobile phone, the topic needs to be addressed further in school, as well as in public discussions, to lead to a deeper understanding.

STUDY LIMITATIONS

Although even lower return rates than our achieved rate of return (37%) for the teacher questionnaires are fairly typical with optional evaluations (Watt et al., 2002), we note that they can skew results, either toward high or low satisfaction. We suggest that the extremely positive results might be skewed due to highly motivated teachers who liked and used the material and who may have been more likely to return the questionnaires. Also, recruitment can be a limitation due to reaching out to established mail servers, instead of casting a wider net to attract more participants. We cannot explain the relatively low response rate, although teachers were made aware of the follow-up during the workshops. We believe that it would have been beneficial to call teachers or write a second email to remind participants about missing responses, as Nulty (2008) proposes, to implicate a commitment. Watt et al. (2002) states that when paper surveys are not administered face to face, the response rates might be as low as for non–face-to-face online surveys. Still, considering liberal conditions that ask for at least 20% by more than 100 participants (Nulty, 2008), we believe that our response rates do show a representation of our methods and materials.

We cannot guarantee the fidelity of implementation through teachers since we were not able to test whether or not teachers implemented the lessons in a manner that was representative of our intent. However, when looking at the subjects teachers chose (reported in question 3), we are confident that most of our main points were selected, but we cannot confirm if they were all brought across correctly and without judging statements. To test this, it would have been necessary to also test students' performance in classes from teachers participating in the workshop versus our own instructed classes, which was not feasible for 93 teachers across Austria.

Although we asked teachers in Austria for the long-term posttest not to mention specific terms, it is possible that a teacher or a student made a well-intentioned suggestion (e.g., "remember the lab day when we did . . .") that could have altered the data. In general, feedback from teachers and students still seems to be limited when written. Students' changes in behavior or thinking about the environment are not directly measurable, as those will be long-term effects.

In general, the positive student test results might not be completely representative for a typical high school student, as the selection method was not random. For the students' classes, one of the teachers we contacted for the project was already known to be interested in the subject and generally teachers would not participate if they thought geosciences to be an unimportant subject. Teachers who volunteered may have self-selected for a favorable predisposition of the topic.

IMPLICATIONS

To emphasize the varied range of application and the linkage among several disciplines such as physics, biology, and chemistry, successful geoscience education needs to combine modern educational tools with applied up-to-date science. This could be an important strategy to address and attract future geoscientists in the classroom and enhance the passion for science by making geoscience more visible—and also support and attract teachers for interdisciplinary teaching (Hattie, 2003; Silverstein et al., 2009).

We feel that providing a workshop for teachers where they were able to take on the role of students and ask questions but also familiarize themselves with the material kit in an informal setting helped engage them in the topic. For those teachers that cannot participate in professional development, an extensive background workbook with ready-to-use worksheets should always be available.

Attending the workshop with other teachers also sparked new ideas for teacher collaborations or project work. It could be beneficial to have workshops for colleagues from the same school to further foster teacher collaboration and thus improve interdisciplinary teaching at schools, especially when it comes to broad and complex topics regarding sustainability.

It seemed to have a positive influence on teachers to engage them in a subject that personally interested them—a subject that is not usually part of the standard curriculum and one that is "something new and exciting." This could also lead to collaborations with a science center nearby. Thus, we suggest that teacher workshops that encompass up-to-date topics include a reference to daily life and also inform teachers in an engaging way, which might affect their teaching and thus help students getting access to more advanced topics.

By having students investigate the science and facts behind the issues and by emphasizing problem-based thinking, we can sensitize students for resources in their daily lives. This might eventually lead to a change in behavior at some point, after it has been repeatedly implemented in different settings.

Oral teacher feedback suggested that the mere bulk of new input (students were targeted with a large amount of new concepts, new information, a new setting, unknown scientists as teachers, and a different topic) might have been too much in one instruction module. Instead, the repetition and elaboration of concepts from our module in other lessons, other contexts, and other grades is needed as the Next Generation Science Standard suggests (NGSS, 2013).

In our case study with students, due to time restrictions, we discussed the topics of each commodity via a presentation wherein we had already provided much of this information. Ideally and with no time restriction, this would be information acquired by students. A way to sum up the acquired knowledge—our resource-intensive consumer behavior, the ecological and social effects of mining for mineral resources, the importance of preserving resources to maintain our system Earth, and our living standards and possible solutions such as recycling—can be debated in a role playing game, which we have tried in stages following the case study. In role playing, students may take on one or more identities such as the following: a mining worker, a farmer who has been deprived of land for a mine, an environmental protection activist, a manufacturer of different parts, a development aid worker, a factory worker, a global organization for sustainable sourcing, a warlord of a conflict county, a trader of commodities, a consumer, a recycler, a vendor, or a politician. It is important that students lead the discussion themselves. During the entire module, there should be no intervention or judgment by the teacher (such as "see how bad this is" or "we should not buy a new phone so often"). Rather, the teacher should, if at all necessary, only guide students with questions so they come up with their own conclusions that represent their own realistic approach.

We recommend that the part of the module implementing the cards should start from grade 9 and above, in order that students have the necessary chemistry background needed to understand the answers. For younger students, a discussion guided by the teacher seems to be more appropriate—something we have tested with classes following our case study. We therefore place the presented module for a targeted age group starting at grade 9, although parts of it can be used for younger students.

Continuous feedback from students and teachers helped refine the module and adapt it to the needs of students and teachers. The data suggest that many students learned and retained knowledge mainly from the practical exercises (disassembling the mobile phones), which stresses the necessity of hands-on exercises. The assessment results demonstrate that such a diverse, complex topic can be taught in school and some knowledge is retained over the short and long term. However, theoretical parts of the topic that had not been covered in hands-on exercises and are not repeated after the visit are not retained as well over longer timescales. We suggest reinforcing difficult concepts in multiple settings (i.e., out of school and in school) might have a stronger impact on learning. In general, we propose that conducting outreach with scientists (as we did in the students' study, in which the first author, as a research scientist, taught the module) is a highly successful way of engaging students and familiarizing teachers with the pedagogical content knowledge, which in turn could play a role in fostering curiosity and an overall appreciation of science.

All our study limitations show that we mostly focused on adapting our module. For a complete investigation of the module and different learning types for the two countries, further research would be necessary.

Last but not least, we would like to cite the headline introduction of InTeGrate modules, which closely resembles our approach: Modules should be "hands-on, data-rich, and socially relevant geoscience activities" (p. 830).

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