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"Reforms in the Teaching and Learning Science"

Based on a symposium that took place in the AACE on the December 2018

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preface

Zaki Kamal, Advocate

President
The Academic Arab College for Education in Israel-Haifa
Speech in the opening of the international conference: "Reforms in Science Teaching and Learning towards the 21st Century"
11-13 December 2018

The dynamic world we live in is a world in which the processes and ways of perception, teaching and research have been changed. In order to track these innovations, The Academic Arab College of Education in Israel puts a priority to hold annual academic conferences in most disciplinary and interdisciplinary fields, particularly in science that develops rapidly. The state of Israel is considered a great country with respect to the number of Noble Prize laureates relative to its size. During the last decade, four researchers have won this prestigious award. We believe that school is the starting point for the creation of educating generation of scientists. Therefore, the purpose of the conference is to promote teaching methods and expose college faculty and students for new researches, which deal especially with reforms in science teaching. In addition, the conference will expose students to success stories of scientists who have overcome obstacles and problems facing them and contradict their stories. In the present era, new opportunities are open to the learners, researchers, and teachers that include a combination of post-modern teaching means. Nevertheless, they cannot replace the skills of the teacher and/or trainer. Therefore, in this international conference, we will integrate researchers to lecture and discuss ideas and models for reforming the way science is currently taught and learned. These advanced methods of teaching may be of interest to student teachers and may enable them to integrate during their studies and their work later. This conference "Reforms in Science Teaching and Learning towards the 21st Century" provides an opportunity for leading scientists from all over the world to discuss important issues and ideas related to reforming teaching and curricula development that are open to the science and its related technological developments.

May we merit increasing science for the benefit of human beings regardless of origin, religion, race, nationality and country; science knows no borders and may peace prevail in the world, particularly in our region.

Introduction

Prof. Randa Khair Abbass

College Head and Rector
The Academic Arab College for Education in Israel-Haifa

The Academic Arab College for Education in Israel is a leading teacher training institute offering a range of bachelor and master's degree programs, in addition to certification programs in practical engineering, extension studies and theatre studies. The college believes in the high value of research and its significant impact on our students as future teachers, and on our communities.

As we know, we live in a dynamic world where the methods and ways of teaching, learning and research are changing at a tremendous rate. Out of commitment to track these changes and to support innovation and creativity in education, the college is keen to organize annual academic conferences in disciplinary and interdisciplinary fields. The current special issue of "Reforms in the Teaching and Learning Science" is in itself based on a symposium, which was held at the Academic Arab College for Education in December 2018.

The 2018 international symposium "Reforms in Science Teaching and Learning towards the 21st Century" hosted leading scientists from all over the world to discuss important issues and ideas related to education reforms and curricula development in the scientific and technological fields of study. The contributions of these discussions have been evident in the scientific discourse and scientific practices at the national and international levels.

The first article in this issue "Reforms in the Teaching and Learning Science" by Muhamad Hugerat, Avi Hofstein and Riam Abu-Much sheds light on the waves of reform in science education in Israel, the United States of America, Britain, Finland and other countries. The article presents the approaches and methods used in order to make the teaching and learning of science more efficient.

James A. Shymansky's article presents a program that provides K-5 science teachers with online professional development resources. Just Ask 2.0 addresses the difficulties usually faced by k-5 science teachers. It provides teachers with "lesson packets" which are designed as professional development resources that are of high quality, of authentic content and that are easily accessible.

In her study "The Design of Instructional Resources Aimed at Improving Visualization in order to Promote Understanding of Chemical Phenomena" Maria Oliver-Hoyo demonstrates two instructional activities aimed at enabling visualization of chemical phenomena via different visualization mode, including acoustic analogy and 3D physical models, to . The activities highlighted in the article are from two different projects that tackled visualization at the nano versus macromolecular scales.

(4) "Thinking Outside of the Box: Using the Arts to Teach About 18 Science in Early Elementary Education" by Vivien Marcow Speiser and Phillip Speiser explores the contribution of arts to teaching science in early elementary education. The article provides helpful definitions of art and science when working with children and teachers. In addition, it emphasizes the significance of wonder and imagination in building a child's understanding of the world.

Tali Tal's article "Not Falling into the Trap of Dichotomizing Formal and Informal Education" undermines the connection between teaching sciences in formal learning environments and meaningful learning. Tal argues that informal learning environments, such as outdoor education, can also yield the same results as formal learning environments do if the focus of educators is on the learning process and how to create meaningful learning.

The article "Phosphorus From the Sustainable Development Goals Towards Transformative Non-Formal and Formal Education" by Christian Zowada, Ozcan Gulacar, Antje Siol and Ingo Eilks explores the importance of phosphorus and phosphates and their necessary integration into chemistry curriculums considering the elements' fundamental role in sustainability debates. The article emphasizes that a uniting approach of socio-scientific issues and the Sustainable Development Goals (SDGs) is likely to result in greater student engagement in science lessons.

"Sustainability: Equipping our Students as Future Citizens, Teachers, and Scientists" by Catherine H. Middlecamp explores sustainability environmental issues including ocean acidification, global climate change, and microplastics in the environment, and how they are related to the carbon cycle. The article suggests that educators should expose students to the above-mentioned issues since they are not only related to learning chemistry, but are directly affecting the world we live in.

In "Contribution of Out-of-School Laboratories to the Enhancement of Scientific literacy," Matthias Streller and Avi Hofstein emphasize the importance of informal science learning for the achievement of educational goals such as the development of scientific literacy. The article focuses on out-of-school laboratories as a source of learning, especially considering its success in Germany. The article calls for the combination of both formal and informal opportunities of learning science and proposes the online portal as a platform to link both formal and informal sites.

In "Regional Networks and Regional Didactic Centres to foster Science Education," Franz Rauch presents a theoretical study of the benefits of regional networks in education and focuses on the Austrian IMST project as an example. These networks have a fundamental role in increasing creativity and innovation in science lessons and are considered a major strategy to support reform in the education system. Noting the major role of these networks, Rauch argues that didactic centers should be organized to meet the needs of regional networks. In the Austrian IMST project, these centers serve as an intermediary between universities and teacher training colleges that cooperate in creating and designing education programmes.

In "Professional Learning Communities (PLCs) of Chemistry Teachers," Rachel Mamlok-Naaman explores the benefits of creating and participating in professional learning communities (PLC) to bring innovation, creativity, and critical thinking into the science curriculum. The teachers of PLCs share their teaching practices and focus on the learning and learning outcomes of their lessons. As a result of this cooperation, teachers can reflect on their teaching and make necessary changes and/or adaptations according to the problems/issues raised in the PLC discussions thus enhancing the teaching culture.

In "Teaching 21st century science with 21st century skills," Peter E. Childs explores current and common problems with science education. Science teaching, both in schools and at the university level, has not changed over the years. Childs warns of the dangers of teaching the same content and practical skills which are likely to result in poor preparation and failures in meeting the needs of the 21st century. The article also represents the most identified skills of the 21st century, in addition to examples of integrating them into STEM education.

In "Sustainability as a Foundation for Accessible and Relevant Science Education," Kenneth M. Doxsee emphasizes the importance of traditional knowledge and its relevance to science education. Doxsee argues that this approach to science curriculum with specific focus on green chemistry and sustainability creates relevant and accessible learning opportunities for students. The article demonstrates the application of this approach to science curriculum in the Pacific Northwest of the United States and emphasizes its equal relevance to other communities around the world.

In "Designing Science Education Learning Environment to Engage Students in Developing Useable Knowledge," Joseph Krajcik, Israel Touitou and Barbara Schneider explore Project Based Learning (PBL) and it brings students to understand scientific aspects. PBL enables students to experience meaningful learning and infer, through activities, why phenomena occur. The findings presented in the study shows that PBL also contributes to students' learning on social and emotional levels besides to their knowledge.

In "Models and Modeling in Science Education," Mei-Hung Chiu discusses the standards of Taiwan's 2018 science framework for grades 3-12 in relation to models and modeling practices in science learning. The new framework focuses on bringing inquiry and practice into the science curriculum and to make the learning of chemistry more relevant to students' lives. This transfer from a macroscopic to a microscopic approach in the 2018 framework aims at enhancing students' thinking competence, including the development of higher order thinking skills and their overall mental models of the topics they learn.

In their research "Pedagogical Content Knowledge and Assessment Knowledge in Teaching the Energy Topic," Gabriella Shwartz, Rana Abdalla, and Yehudit Judy Dori use qualitative and quantitative tools to investigate chemistry teachers' Pedagogical Content Knowledge (PCK) and their Assessment Knowledge (AK) when teaching energy and dynamics in chemistry.

I would like to thank everyone involved in the making of this journal: the authors of the articles, the critics and reviewers who read and comment on the texts, and the producers who complete the work of publishing. I hope that the readers of this issue will find their reading worthwhile and illuminating and for them to consider contributing to the upcoming issues of Daruna.

Reforms in the Teaching and Learning Science

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Throughout the last 50 years, the goals and its related objectives for science teaching and learning have undergone changes several times; often leading to reforms in the way in which the curriculum content was taught and science was learned. The five key factors that have influenced a change in curriculum goals for teaching science are the learners, the teachers, the content, the pedagogy of teaching both in and out the school, and the assessment of students' achievement and progress. The symposium in the Haifa Arabic College is a good opportunity to share experiences from different countries and different educational systems on goals, curriculum, teachers' professional development and students' experiences in different learning settings.

In September 2016, The Israeli Academy of Science organized a symposium focusing on conclusions related to the reform in science teaching in Israel based on the "Tomorrow 98" document that was initiated by the Ministry of Education in 1992. The 45 recommendations included in this report were the basis for comprehensive reform in the way science is taught (and learned) in K-12 classes in the educational system in Israel. The development of learning materials, new instructional techniques and the implementation of new models for the in-service and pre-service professional development of science teachers, were mainly conducted in the academia (universities and colleges) coordinated and initiated by the Israeli Science Teaching Center (MALAM). The key findings related to this reform were the development of science and technology curricula for all students attempting to make science education more relevant to the learners.

Reforming science education is conducted in recent years in many countries around the world to include UK, USA, Germany, Singapore, Austria, Taiwan, Finland and many more. These reforms that were reviewed (as a preparation phase included among other issues the following: goals, the curriculum (content), teachers' professional development and its related pedagogy and instructional techniques (to include teaching and learning with ICT) and the alignment of formal and informal science learning. The report that was prepared and published (see link) (published in Hebrew and Arabic) described the National Science Education Standards in the USA and also the new Standards mainly developed by National academy of Science due to the non-centralized nature of the educational system that prevails in the USA.

Other countries (e.g. UK and Germany) developed curricula based on the model of context-based approach. The Key idea that underlines this approach is highly based on need to make the learning of science more relevant to the student. In Finland (among other approaches), a genuine attempt was made to use ICT in the context of teaching and learning. It was found that the implementation of this approach was slow than expected. This was mainly due to the teachers' lack of experience and necessary skills. We tried hard to find commonalities between the various reforms in different countries and we can sum-up that successes of science education reforms is highly depend on the following: Long-term, design, holistic approach, involvement of science teachers in the R & D approaches (to include CPD), and continuous evaluation and assessment processes.

An Online Professional Development Resource for K-5 Science Lessons: Just ASK 2.0

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Introduction

Teachers in the United States at all levels are being asked to rethink their teaching to better reflect the Next Generation Science Standards (NGSS) that focus on the integration of science's three dimensions: science and engineering practices (SEPs), disciplinary core ideas (DCIs) and crosscutting concepts (CCCs) (National Research Council 2012; NGSS 2013)[1]. At the same time, Common Core State Standards in mathematics and English language arts (ELA) are asking teachers to integrate mathematics and ELA into content areas such as science through the use of authentic text material. Given the limited availability of curriculum materials designed specifically for NGSS, these calls for content integration are challenging for all K-12 teachers, but especially for K-5 teachers who are often reluctant to teach science at all, let alone three-dimensionally (Madden 2016). The task of helping teachers understand and implement three-dimensional (3D) teaching is especially challenging for school districts that do not have on-site staff with the necessary expertise or the funds to bring in consultants to provide the expertise needed (Dede, Ketelhut, Whitehouse, Breit, McCloskey, 2009).

Over the past decade it has become increasingly clear that a promising way to deliver educational resources, including PD for teachers on a large scale is by way of the internet. But online resources for teachers have been generally limited to lesson plans, assessments, and supplementary text material (e.g., Open-Content Learning Portal (Devaney, 2007), Teacher Tube, or Teachers.Net). While digital repositories of such materials are valuable, they rarely provide expert analyses of lessons, teacher reflections and suggestions, or examples of teachers interacting with experts or other teachers—all critical to the enhancement of teachers' science knowledge and classroom practices (Duschl, Schweingruber, & Shouse, 2007). Schools have also been slow to make use of teacher study groups or other collaborative support structures and we know from experience that teachers are more likely to participate in science if they have the support of other teachers. Just ASK 2.0 addresses these challenges by providing a source of "lesson packets" that are aligned to grade-level NGSS learning goals and that integrate or "blend-in" mathematics and ELA learning goals. The lesson packets include lesson plans and videos of teachers teaching and reflecting on their lessons and videos of other teachers commenting on the lessons. The lesson packets are designed to serve as a professional development (PD) resource that is high quality, authentic and easily accessible.

Just ASK 2.0 is built on the 25+ years of projects in which K-5 teachers developed and implemented blended science lessons (Shymansky et al., 2004; Shymansky et al., 2011; Shymansky et al., 2013; Romance, Vitale & Miller, 2015; Romance & Vitale, 2017). The research on blended learning consistently shows that gains in the science knowledge of teachers and their students are achievable when the teachers integrated science with reading or mathematics.

Support for online blended instruction

A summary of research on blending science with other curricular areas suggests gains in both student science achievement and affect (Czerniak & Johnson, 2014). In particular, there is evidence that the incorporation of literacy activities enhances both boys' and girls' science learning and promotes their motivation for learning (Mantzicopoulos, Patrick & Samarapungavan, 2008; Patrick, Mantzicopoulos & Samarapungavan 2009). Our own studies have consistently shown that significant gains are produced in the content knowledge and pedagogical practices of teachers and the science knowledge of their students when science is integrated with other curricular areas (Shymansky, Yore & Anderson, 2004; Shymansky, Wang, Annetta, Yore & Everett, 2011; Shymansky, Annetta, Yore, Wang & Everett, 2013). Focusing on science, mathematics, and literacy learning goals at the same time also gives teachers a chance to teach science without feeling they are taking time away from what they often think of as the "more important" areas of reading, language arts, and mathematics.

Online PD is attractive because it can provide asynchronous, just-in-time assistance and access to experts that may not be available to many schools, making them more widely useable than traditional workshop-based PD (Dede et al., 2009, p. 9). Sharing online materials that teachers themselves have created also has been shown to be effective. For example, Borko (2004) points out that artifacts such as lesson plans, videos of lessons, and samples of student work can be used to "bring teachers'

1. Currently 16 states have adopted the NRC Framework-based NGSS as written. But numerous other states have developed standards substantially reflecting the structure and content of NGSS.

classrooms into the PD setting…a critical component of successful PD" (p. 6). In addition, teacher analyses and discussions of video recorded lessons have been shown to be an effective PD tool in several areas of STEM PD (Roth et al., 2011; Sherin & van Es, 2009).

Just ASK 2.0 builds specifically on the research of three projects. In Science PALs (ESI 9896142) (1994-1998), the first in the series, teachers were shown how to use ideas found in children's fictional literature (e.g., Goldilocks and the Three Bears) as a springboard for science investigation. The process of examining-analyzing-testing the science ideas in the literature created a need to do more reading, writing and language arts. Thus, the ASK "adapting science for kids" idea was born. The lesson adaptation strategy succeeded in bringing to PD teachers who had previously been reluctant to teach science or participate in science PD and significantly impacted children's attitudes toward and achievement in science (Shymansky et al., 2004).

Science CO-OP (ESI-9911857) (2000-2005) was especially successful as a "Local Systemic Change" (LSC) project in increasing the hours of PD that K-6 teachers took part in, the amount of time they spent teaching science, and their use of science inquiry strategies. Achievement data from state tests showed that the percentages of students rated "proficient" or "advanced" improved by 10 percentage points on the Missouri test and by 6 percentage points on the Iowa test (Shymansky et al., 2011; Shymansky et al., 2013).

The recently completed project "Teachers Helping Teachers Teach Science: Just ASK (DR K-12 0733195) (2007-2013) resulted in the creation of a website through which teachers and PD providers nationally have been able to access blended science lesson packets. The website contains lesson plans and annotated videos for 73 ASK lessons developed prior to the NGSS publication[2]. In its first 32 months of operation 1,222 individuals (including teachers from 830 schools in 43 states and pre-service teachers and teacher educators from 293 colleges) visited the website 33,943 times to view and/or download ASK lesson plans and videos.

NGSS "three dimensional" science teaching

Architects of the NGSS approach to science teaching and learning describe a process in which lessons take students on "a coherent path toward building disciplinary core ideas and crosscutting concepts, piece by piece, anchored in students' own questions" (Michaels, Moon & Reiser, 2017). The approach makes use of three dimensions (3Ds) of science: science and engineering practices, disciplinary core ideas, and crosscutting concepts. Successful 3D teaching and learning incorporates multiple practices of science to help students understand and explain phenomena in the natural world in terms of basic science principles. 3D lessons typically extend for several weeks and incorporate multiple science practices (e.g., asking questions, planning investigations, collecting and analyzing data, creating explanatory models, and communicating results). Lessons also highlight ideas that cut across all fields of science, such as ideas about patterns, cause and effect, stability and change, and systems and system models.

Teaching K-5 science "four dimensionally"

When the ASK idea of blending science with other areas in the curriculum is linked with the NGSS three dimensions of science, the result is a "four dimensional" (4D) science teaching strategy. The Just ASK website currently contains a selection of lesson packets featuring full class videos along with teacher and colleague reflections and analyses of video vignettes. We are currently producing new K-5 ASK-NGSS lesson packets and updating 25-30 of the ASK lesson packets made prior to the release of the NGSS in 2013 to show how to make the lessons more "NGSS-compatible." The updating process involves having an expert ASK/NGSS teaching colleague analyze lessons contributed by K-5 teachers in terms of the lesson's NGSS compatibility and its effectiveness as a blended lesson. A sample of an updated lesson plan on "Life Cycle of Butterflies" is shown in Appendix 1. The new ASK-NGSS and updated ASK lesson packets will be made available on the Just ASK 2.0 website.

The future of online PD

4D lesson packets lend themselves to a variety of PD uses: (1) by individual teachers trying to understand the NGSS 3D teaching approach and looking for 3D science teaching ideas; (2) by teachers who function as informal communities of practice who are working together to understand the implications of the NGSS for teaching and learning; (3) by school district leaders who want to organize a more formal staff development program focused on NGSS; and (4) by science methods instructors who want to promote blended 3D science teaching for pre-service teachers.

Given the response and visits by practicing teachers (>2,000 per school year month) and elementary science methods instructors (~300) to the initial Just ASK a Teacher website, the potential of the Just ASK 2.0 website to impact K-5 science teaching at the in-service level and teacher preparation at the pre-service level is substantial. While there is no way to accurately predict the actual number of visits a website containing a full set of 4D lesson packets addressing all K-5 NGSS PEs, SEPs, DCIs and CCCs will generate, that number could easily exceed 50,000 or more teachers per year. The online character of Just ASK 2.0 also makes it possible to continually add lesson packets to the site. Finally, and

2. Go to: http://justaskateacher.com/joomla/index.php?option=com_mtree&task=att_download&link_id=83&cf_id=24 to view a sample of a lesson blending website packet.

perhaps most importantly, the lesson packets will continue to be available online to in-service teachers, PD leaders and pre-servic teachers at no cost.

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Appendix A

A Grade 1 Lesson on Life Cycle of Butterflies Updated to NGSS and CCSS ELA-Literacy Standards

Important Note: The ASK lesson plan and videos in this lesson packet were made prior to the release of the Next Generation Science Standards (NGSS). Comments by an ASK-NGSS expert teacher have been added to the lesson on ways to make the lesson "NGSS-Compatible." The materials in this packet are offered for the purpose of stimulating discussion among teachers--discussion that can lead to improved practice, Although the materials may have exemplary aspects that you may wish to use, they are not intended to represent a model for teaching this or other ASK-NGSS lessons. Rather, we invite you to examine the lesson in terms of its effectiveness in (1) promoting science inquiry, (2) facilitating instruction in another curricular area, and (3) addressing relevant NGSS, local, or state standards.

1. ASK Lesson Plan

Lesson Overview: I adapted this inquiry science lesson to include language arts for my first-grade students. Science is high interest for students and so observations and class discussions is an engaging pre-writing activity.

In this lesson I expect students to learn that some things change and some things stay the same. With a brief review and observations on the changes that our caterpillars are going through, students discuss what makes things change and identify other things that will change or stay the same. Though this might be a difficult concept for students to master at this age, this lesson develops the idea of change in nature. Mastery will come later.

My intention is that students will come to understand the process in which caterpillars change and will predict the final stage of this process. I'm adapting the lesson to include language arts so that students will also identify pictures and put them into the correct category of things that change and things that don't change. Using inquiry questions can effectively lead students to understand the science behind what they are seeing happen to the caterpillars. Predicting can be challenging for students so incorporating it into this activity where students have a base knowledge of caterpillars can make it easier for them to learn.

Engage: Use inquiry questions to learn students' knowledge of the concept of change. Review vocabulary words with students to insure understanding. Through inquiry, the teacher makes connections to prior knowledge and builds to prepare the students to make predictions. This is a good time to check for any misconceptions students may have.

Explore: Observing and naming the parts of a caterpillar. Use inquiry techniques to develop student understanding of how caterpillars have body parts designed to meet their needs. Use the legs of a caterpillar as an example. Students explore the caterpillar to see how they use their legs to meet their needs.

Explain: As the caterpillar in the cocoon grows and gets bigger and bigger, the protective wrap around it stretches until it bursts open. Then connect this concept to how we change through our life as we grow bigger and bigger. This is where the science concepts are developed. Inquiry is an effective method of developing understanding.

Extend/Elaborate: Expand the idea of change to other living things life tree. This extended the students understanding of the concepts often leading them to seek more information. The extension of the matching game to teach the language arts principles, the teacher taught several concepts with one activity.

Evaluate: Use a game to evaluate whether the students understand the vocabulary terms and changes in caterpillars. I used the game as a formative assessment to ensure that students understood the concepts presented the day before in science. I monitor what students are learning in a game and with a worksheet. In the game students pick a card and tell if it is something that changes or something that stays the same. After the game and group discussion, I use a worksheet that will have students individually identifying things that change and things that stay the same. This was a very effective lesson, both in teaching science and language arts!

2. NGSS and CCSS ELA-Literacy Suggestions

Performance Expectation 1-LS-1: Students who demonstrate understanding can use materials to design a solution to a human problem by mimicking how plants and /or animals use their external parts to help themselves survive grow, and meet their needs.

Though the students are not actually designing a solution to a problem in the "explore" activity, they are observing how the caterpillar uses it body parts to meet its needs. To make this activity more NGSS-compatible, students could pose a simple problem of retrieving an object that would require them to crawl much like a caterpillar.

Disciplinary Core Idea LS1.A: Structure and Function Organisms have external parts. Different animals use their body parts in different ways to see hear, grasp objects, protect themselves, move from place to place, and seek, find, and take in food, water, and air.

To address the NGSS, students could research organisms other than caterpillars to learn what special features other animals have that help them survive. This could be a good learning center, or at-home project. The research could then be turned into a matching game so the students could learn the information independently.

Disciplinary Core Idea LS1. D: Information Processing Animals have body parts that capture and convey different kinds of information needed for growth and survival. Animals respond to these inputs with behaviors that help them survive.

An effective way to reinforce the NGSS would be to have students move like animals, hopping like rabbits or kangaroos, jumping like a deer, slithering like a snake, hunting like a cat or tiger, running like a mouse. Students could then work in pairs or small groups to do charades to guess what animal they are imitating.

Cross Cutting Concepts: Structure and Functions The shape and stability of natural and designed objects are related to their functions.

The teacher effectively addresses this NGSS with her guided inquiry by using questions to lead students to a deeper understanding of the concepts and to facilitate more student involvement and discussion that is relevant to students. By the end of the lesson students are leading their own inquiry.

Influence of Science, Engineering and Technology on Society and the Natural World: Every human-made product is designed by applying some knowledge of the natural world and is built with materials derived from the natural world.

Do humans make changes as caterpillars do? Do humans molt? (we do lose hair and skin?). Are there any man-made products that help us deal with changes? (brushing or combing hair, loofahs for skin). Though the students are not actually designing a solution to a problem for this activity, they are observing how an animal changes to meet their needs. An extension of this activity would be to actually design a solution for a problem.
Science and Engineering Practices Constructing Explanations and Designing Solutions: Builds on prior experiences and progresses to the use of evidence and ideas in constructing evidence-based accounts of natural phenomena and designing solutions.

To better meet the spirit of the NGSS, students could make a model demonstrating the changes a caterpillar makes as it goes through the stages of development. In the course of doing this, the students could discuss how humans make changes to our clothing, transportation, housing to accommodate the changing needs during the stages of human life.
CCSS ELA-LITERACY. L.1.5: With guidance and support from adults, demonstrate understanding of word relationships and nuances in word meanings.

This standard is well covered with the activities in this lesson with the mastery of vocabulary, both science and language terms. Application of vocabulary terms will demonstrate student understanding of NGSS. Science journals are a help for students to review the terms throughout the year.

CCSS ELA-LITERACY.L.1.5A: Sort words into categories (colors, clothing) to gain a sense of the concepts the categories represents.

The categorizing pictures of animals certainly fits this standard as well as the NGSS. Matching games used as take-home activities or in learning centers can also extend this standard.

CCSS ELA-LITERACY L.1.5B: Define words by category and by one or more key attributes (e.g., a duck is a bird that swims; a tiger is a large cat with stripes).

This is another example of Language Arts and NGSS combining well. Highlighting changes the caterpillar makes emphasizes it's attributes. Some of the suggested activities (students making animal moves and matching games) also fulfill both NGSS and Language Arts Standards.
CCSS ELA-LITERACY L. 1.5C: Identify real-life connections between words and their use (e.g. note places at home that are cozy).
This was well presented with the real life changes that caterpillars go through, a real-life connection that many of the children were familiar with which gave it more meaning.

3. ASK Lesson Reflections

My Reflections on the Lesson: Even though this is a difficult topic, the lesson went well. The concept of "change" and "stay the same" is hard for first graders. It is not easy for them to recognize that everything changes in time and also to differentiate between changing due to external actions (such as breaking an object) and things that change regardless of outside actions. I hope you can suggest more effective ways for teaching this.

The game did support the concept very well and gave students individually the opportunity to demonstrate their understanding. Students always love games, even when they are learning. It did take extra time making sure that each child got an opportunity to turn a card in the game. Because we ran out of time, I had students do their worksheet the following day for their morning center.

4. View my video

Go to http://justaskateacher.com/joomla/charles/Videos/ASK003VSTCLifeCycleButterflies5Gr1LA.mp4
to view my video with clips from my lesson and some comments from me.

The Design of Instructional Resources Aimed at Improving Visualization in order to Promote Understanding of Chemical Phenomena

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Abstract

Effective visualization of chemical phenomena may draw from pedagogy, instructional design, and/or technology to "observe" objects or processes that cannot be seen by the naked eye. Our instructional resources have shown effectiveness at promoting understanding of chemical phenomena via different visualization modes. The robustness of these resources rises from several aspects including the frameworks guiding their design, the strategies chosen to implement them, and the models used to make the science "visible". These aspects will be highlighted with exemplar activities from two different projects that tackled visualization at the nano versus macromolecular scales. While analogies were used to assist students in connecting core scientific concepts to the nanoscale, more tangible 3D printed models were used to study macromolecular structure and interactions.

Keywords: visualization, instructional resources, analogies, 3D printed models

Introduction

Instructional resources for undergraduate chemistry education tend to be developed by teaching faculty without documenting the frameworks used in their design and the assessment that validates their use and relevance. This paper illustrates the foundational layer for two radically different instructional resources aimed at improving visualization of chemical phenomena; an analogy connecting core chemical principles to principles of the nano world, and a tactile activity that uses 3D printed physical models to visualize interactions at the macromolecular level. The assessment of both instructional resources will be briefly discussed in order to provide evidence of their effect on students' understanding, specifically understanding of localized surface plasmon resonance (acoustic analogy), and noncovalent interactions in macromolecules (3D physical models).

PART 1: ACOUSTIC ANALOGY

FRAMEWORK (Gentner,1983; Gentner and Markman, 1997)

Gentner's structure mapping framework guided the design of the acoustic analogy to connect to the nano phenomena of localized surface plasmon resonance (LSPR). The foundation of this framework relies on exploiting as many "object relations" as possible between the base knowledge domain and the targeted domain. Relations describe how particulars of an object interact with each other and these take precedence to object attributes or basic properties of that object. In this case, the base domain consists of core physical and chemical concepts that will be applied to the targeted domain, LSPR. A robust design will maximize the number of relations that map from base to target.

ACTIVITY (Muniz and Oliver-Hoyo, 2011)

LSPR is a phenomenon exhibited by metallic nanomaterials when the oscillating conduction band of electrons of the particles resonates at a particular frequency. Such resonance depends on the identity of the metal and the size of the particle. These two properties are used to compare the acoustic behavior of tuning forks to the optical behavior of metallic nanomaterials.

Students start by measuring the length of tuning fork prongs, then striking them onto a hard surface, and finally ordering the tuning forks according to the pitch frequency produced. Students observe that the tuning forks exhibit oscillatory behavior and that an external force (striking) is required to induce such oscillation. They repeat the same process with brass tuning forks analogues (same length but different composition) observing how the metal composition, aluminum or brass, changes the frequency of sound observed. The learning objectives include students to be able to compare the two sets of data and examine how as the tuning fork's length increases, their pitch decreases, and how the composition affects the wave properties via observed pitches.

Data is mathematically treated when students explore the mathematical implications of the properties observed (Narayan, 1996; Rossing, et al., 1992). Students calculate the tuning fork sound frequency using Equation 1 and then change frequency into wavelength to plot the wavelength of sound versus the square of prong lengths for both brass and aluminum tuning forks (Figure 1).

$$f = \frac{\pi}{8L^2}\left(\frac{EK^2}{\rho}\right)^{\frac{1}{2}}$$

Equation 1 where E = Young's modulus, K = radius of gyration (or cross sectional prong area), r = density of material, L = prong length.

From these plots, students observe that the wavelength increases (as frequency decreases) with increasing prong length, which is the key relation to be mapped to LSPR of nanomaterials in the target domain. They also observe that the composition of the tuning fork affects the plotted lines but not the relation observed. This is mapped to the composition of the nanomaterials.

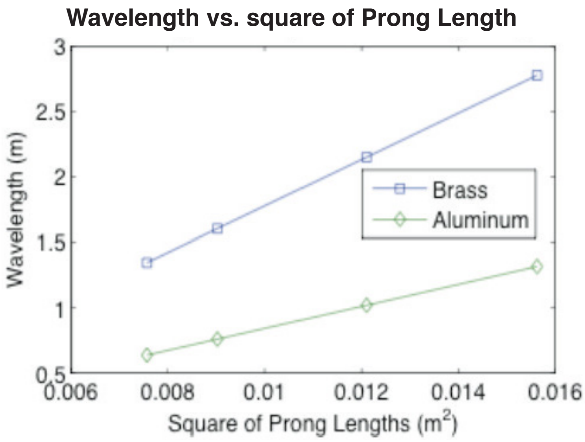


Fig. 1: Plots relating wavelengths of sound to prong lengths of tuning forks with different compositions.

To reinforce these principles, students confirm visually what different frequencies of sound waves look like using two simulators: a beat frequency simulator and a transverse & longitudinal simulator (Waves and Sound Physics, 2000). The beat frequency simulator consists of a virtual oscilloscope with sliders to control frequency, while the second simulator uses a rod to model how mechanical waves propagate through a metal in which the Young modulus and density are altered. With these principles at hand, which constitute the base domain, the connection to the target domain is approached.

Gold nanorods solutions of different aspect ratios (short, medium, and long) are used to obtain UV-Vis spectra of the solutions. Nanorods are anisotropic where the transverse direction (x, y plane) remains constant while the longitudinal direction (z axis) grows out. Students observe how the secondary LSPR band (the nano effect) in the UV-Vis spectrum red-shifts with increasing length (longitudinal average length). The relation between the Al alloy tuning forks and the Au nanorods is established as the resonance frequency decreases with increasing length in either case. Figure 2 shows students UV-Vis spectra for two average size Au nanorods: short (approximately 1.5) and long (approximately 4) aspect ratios (ratio between the longitudinal and transverse axes). The synthesis method for the nanorods is well established and either the instructor or the students themselves may prepare them during the laboratory session (Nikoobakht and El-Sayed, 2003).

Finally, students relate statistically equivalent sized Au and Ag nanoparticles to the tuning fork data as they observe that the LSPR peak in the UV-Vis spectra is at significantly different positions (~100 nm) due to the difference in composition. This relation between Au and Ag nanoparticles maps to the different alloys of tuning forks.

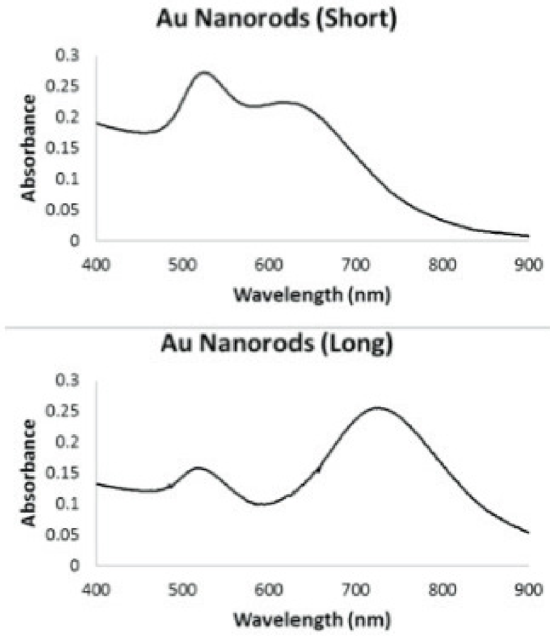


Fig. 2: Representative spectra for short versus long Au nanorods.

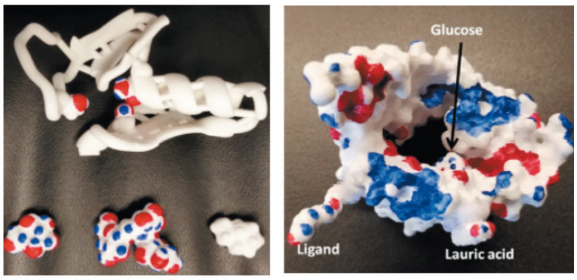
PART 2: TACTILE MODELS

FRAMEWORK

The cognitive model of drawing construction served as the framework to solicit and document externalization of students' mental models through learner-generated drawings depicting target concepts (Van Meter and Garner, 2005; Van Meter and Firetto 2013). This model promotes self-reflection and supports integration of multiple forms of media in order to achieve deeper understanding. Drawing construction was used as the guiding pathway to not only gain insight into students' mental models but also to assess students' understanding. In order to maximize the benefits of drawing construction, physical 3D printed models were created for students to manipulate while exploring noncovalent interactions of macromolecules.

ACTIVITY

A set of 3D printed models was created to study molecular interactions starting at the small molecule level and progressing to the enzyme-substrate complex level. The instructions on how to create such models have been published elsewhere (Cooper and Oliver-Hoyo, 2017). Figure 3 shows two of these models: a) the active site of hexokinase I with glucose, isomaltotriose, and ethylcyclohexane shown at the bottom from left to right, and b) a glucose transport protein with glucose on the inside protein pore while the ligand and lauric acid are on the outside of the protein surface. As can be observed, these 3-dimensional physical models are highly detailed providing a realistic and accurate depiction of the complexity involved. The topics studied using the complete set of 3D printed models include: effects of structure and interactions on boiling point, noncovalent interactions, secondary and tertiary structures, solubility of membrane proteins, electrostatic forces, polarity of macromolecules and enzyme-substrate interactions.



(a) (b)

Fig. 3: 3D models designed as hands-on instructional resources to support students' investigations of macromolecular interactions.

This activity was conducted in a modular approach where students explored the topics relying on the models during weekly sessions, dedicating 15-20 minutes each session, and taking place for 6-8 sessions during the academic semester. Both the content level and the complexity of the models were scaffolded during the semester making sure that the students have had the necessary support in order to be able to draw acceptable representations of the phenomena under study. Student worksheets were created to guide the use of the 3D printed models in the exploration of the specific topics and to document how students visualize the interactions. For example, the glucose transport protein depicted in Figure 3b was used to explore membrane solubility and the representations focused on comparing locations of polar and nonpolar sidechains both within the pore of the protein and on the exterior of the surface. Guiding questions ask students to compare the electrostatic and vine representations of glucose and lauric acid to the representations of the protein to determine what faces of the molecules will interact. Based on this examination, students constructed drawings representing their selections to the most likely solvent for the exterior of the protein, the most likely solvent for the interior of the protein, and the molecule that they predict would travel through the pore. These aspects connect structure to protein properties and a representative student drawing is shown in Figure 5b.

RESULTS AND DISCUSSION

Qualitative methods of analysis were identified as the most appropriate methods to assess data obtained from the use of both instructional resources highlighted here. The main goal of each study was to be able to show that the design of the instructional resources was conducive to students' understanding by facilitating the exploration of the topics at hand. In answering the research questions for each study, the robustness of the instructional resources was revealed. In the case of the acoustic analogy, the study looked for evidence of analogical transfer after students completed the activity therefore, after one exposure to the analogy. In the case of the tactile models for biochemistry, the focus was on evidence of knowledge integration as this activity was a prolonged and systematic exposure to the use of models during a semester-long intervention.

PART 1: ANALOGICAL TRANSFER

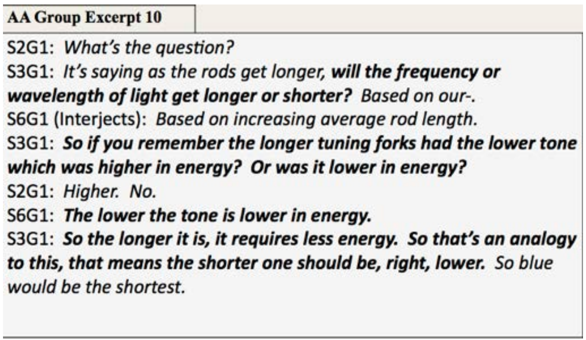
Participants included 24 students that completed the acoustic analogy during a laboratory session. The data collected consisted of: individual student pre-activity interviews to ascertain background knowledge, students' group discourse within their small group settings, and individual student post-activity interviews. Data was fully transcribed and analyzed to uncover patterns and tendencies via open coding. Each of the codes was applied to the data in order to ultimately address the following research questions:

Do the newly developed instructional materials promote in students the ability to effectively map core concepts into the realm of nanochemistry?

Does analogical transfer enable students to develop a more scientifically normative viewpoint on both core and nano knowledge domains?

Codes related to processes students depended on at approaching answering activity questions and included: physical observation statements

& categoricals, misconceptions, reformulations (corrections to incorrect statements), background codes invoking students' prior knowledge, and instructional intervention when students asked the instructor for guidance redirecting the discourse. The most useful code was "comparison and contrastive statements" where students compare one component of the activity to another as it directly revealed analogical transfer. An example is shown on Figure 4 where students in group 1 (G1) directly connected the concept of increasing prong length and increasing wavelength of sound to the red-shift in the longitudinal plasmon mode of the electronic absorption spectrum. Note in particular the comparison and contrastive statement of student 3 (S3G1) expressed after some discussion.



AA Group Excerpt 10

S2G1: *What's the question?*
S3G1: *It's saying as the rods get longer,* ***will the frequency or wavelength of light get longer or shorter?*** *Based on our-.*
S6G1 (Interjects): *Based on increasing average rod length.*
S3G1: ***So if you remember the longer tuning forks had the lower tone which was higher in energy? Or was it lower in energy?***
S2G1: *Higher. No.*
S6G1: ***The lower the tone is lower in energy.***
S3G1: ***So the longer it is, it requires less energy. So that's an analogy to this, that means the shorter one should be, right, lower.*** *So blue would be the shortest.*

Fig. 4: Excerpt from group 1 discourse showing analogical transfer

The evidence of analogical transfer came from both group discourse and post-activity interviews. No evidence of analogical transfer was found on pre-activity interviews. While analogical transfer was present in all groups, it could not be documented for all individuals. This is an indication that reiterates the importance of discourse in reaching deeper understanding (Muniz and Oliver-Hoyo, 2014).

PART 2: TACTILE MODELS

Over 50 students participated each week in the use of the 3D printed models. Students self-assembled in groups of 3-5 students per group. Worksheets for each session were collected and scored individually. Data consisted on the answers to drawing prompts included in the worksheets. An open coding scheme was developed focusing on the features deemed relevant to the study of noncovalent interactions and structure-function relations. The study focused on monitoring indicators of knowledge integration present in student-generated drawings.

Analysis of students drawings revealed that: a) a number of codes were frequently found beyond the introductory activity, b) certain codes were explicitly connected without prompting, c) students presented certain features in different perspectives, and d) students incorporated concepts not discussed in the activities into the drawings. The significance of these results lies in the fact that these patterns represent manifestations of knowledge integration. For example, the appearance of a particular code in different worksheets (sessions) implies that the student was able to recognize the relevance of the feature at the first exposure to it, then considered it to be important to convey a particular aspect in subsequent generated drawings, and incorporated it as knowledge was taking shape. These processes of selection, sorting, articulation, and addition are at the core of knowledge integration. The same applies to code co-occurrences when students linked two different features in their drawings without prompting. As an example, students connected electron density with polarity and represented these codes linked in their drawings as shown in Figure 5 for the enzyme-substrate (left) and membrane protein (right) sessions. The coloring of the protein pore reflects correct convention on electron density distributions.

Fig. 5: Code co-occurrence of electron density and polarity in two different sessions exploring two different topics: enzyme-substrate interactions (on the left) and membrane proteins (on the right).

Evidence of knowledge integration was manifested primarily by three modes coded from students' drawings: codes appearing in multiple sessions, code co-occurring and linked by students without prompting, and codes revealing prior knowledge external to the activity (Babilonia-Rosa, M. et al, 2018). The instructional resources were shown to promote student engagement with minimal intervention (Cooper and Oliver-Hoyo, 2017). The series of models used in sequence supported student understanding of structure-property and enzyme-substrate relations as evidenced from manifestations of knowledge integration.

CONCLUSIONS

The design of our instructional materials benefitted from the frameworks chosen to guide our efforts towards the intended learning goals as well as to their assessment. Evidence of the robustness of these instructional resources comes from qualitative data that demonstrated how their use facilitated students' deeper understanding of the concepts at hand. The instructional materials highlighted here approach the visualization of chemical phenomena in radically different ways. While the acoustic analogy tackles concepts via an abstract visualization pathway (analogical transfer), the use of the 3D physical models facilitated the study of structure and function via a tangible experience. We successfully utilized a framework for analogy to promote analogical transfer from core principles to the nano domain (Muniz and Oliver-Hoyo, 2011 & 2014) while a drawing construction framework allowed an insight into students' mental models of biochemistry principles (Cooper and Oliver-Hoyo, 2017; Babilonia-Rosa, M. et al., 2018).

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Thinking Outside of the Box: Using the Arts to Teach About Science in Early Elementary Education

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Abstract

Science is something that students do, encouraging inquiry, analysis, problem solving and the use of their creativity. Integrating the arts into the science curriculum is an effective way for teachers to keep students engaged and meet society's demand that students have knowledge and experiences in a highly scientific and technological world. Integrating the use of drama, visual arts, dance, poetry, and music engages students physically, intellectually, and emotionally and can interact with science to multiply learning about life skills, key concepts, patterns and themes. This paper will present foundational integrated arts pedagogical principles along with practical examples for how educators can integrate the arts into their teaching.

Keywords: Arts, Creativity, Creative Process, Learning, Science

Introduction

The Arts, when used in the service of humanity are important tools that support human development and learning. Young children ages one to five are sensory learners who use their developing senses to explore their world. One-year olds may know objects exist even when hidden, and actively search for out-of-sight objects. Games such as hide-and-seek, rhythm and rhymes songs, etc. become the centre of existence for learning and development. At age two children expand their range of sensory explorations, running their hands over things (tactile learning), roaming and searching in and out of closets, doors and just about everything (kinaesthetic learning). They identify familiar objects by touch and begin to use imitation and repetition as they observe others using objects. By age three children begin to label objects as hard or soft, large or small, heavy or light and also begin drawing shapes of objects, circles, squares, etc. Thus begins the long process of learning about patterns, concepts and comparisons, still exploring their world through their senses. At age four this sense of exploration begins to reach new levels of sophistication by attending to objects and events in a more planned and structured manner. Children begin building with blocks, string beads, draw recognizable representations of objects and begin to represent objects in relation to one another. This is a major step towards socialization and individuation- the beginning towards developing a 'sense-of-other' in relation in the world. At age five the new developmental breakthroughs are amazing. Children have a wealth of conceptions about objects and how they work. Symbolic thought has begun to emerge with an ability to mentally or symbolically represent objects. And actions and movement increasingly become more planned and goal directed. Language has become more sophisticated and cognition begins to develop alongside sensory learning. The amazing part of learning and growth, integrating sensory and cognitive learning is a cross-cultural and universal phenomena and a process that all children go through in all countries. All children learn through exploring their world through their senses- touching, tasting, motion/kinaesthetic moving, acting and dramatic playing, visual representations/drawing, sounding and music making. This process of wonder and excitement of discovery of language and the world around us that emerges for the child is deeply rooted in imagery, imagination, metaphor and analogy. The child is a natural 'thinker and doer outside of the box'. As the child enters elementary school these are the learning foundational building blocks that the child knows best as they further begin to master the language arts of reading, writing and comprehension. This of course is also applied to all other areas of study including history, mathematics and the natural sciences. This paper will explore how the arts- visual art, dramatic play, movement, music, storytelling/narrative and poetry can be integrated into teaching science in the elementary school. The term Art and Arts will be used interchangeably to mean all of the arts. When we wish to refer to the visual, plastic arts of drawing, painting, sculpting, etc. we will use the term visual art or visual arts.

Discussion

The artist is often searching for meaning alongside a flirtation with the unknown. We consider this the essence of inquiry.

Art can produce unexpected insights that defy carefully calculated rubrics, designed to predict outcomes. Artists thrive on uncertainty. In teaching through the arts, we must take risks and set goals that challenge the status quo, using our expertise as artists to illuminate new pathways toward a more just world. But must inquiry through art making be restricted to the artist? We need broader definitions in education that are more inclusive and allow all children and teachers to access the role of artist.

Here are a few working definitions of Arts and Science that we find very helpful when working with children and teachers.

Art comes from the root ‘ar’, which meant ‘put things together, join’. Putting things together implies skill: hence originally from the Latin ‘ars’ which means ‘skill’. One can infer from this early definition that an Artist is one who ‘Puts Things Together with Skill’. We add to this definition, one who puts things together with skill, within a heightened state of sensibilities. This broadens our definition to allow all of us to claim some degree of artistic expression. The child uses their artistic expression in the service of learning and exploring their world.

The epistemology of Science simply means knowledge. It comes from the Latin ‘scientia’- to know. It passed from ‘knowledge gained by study’ to a ‘particular branch of study around the 1800’s. The term ‘Scientist’ was coined in 1840 by William Whewell when he wrote, ‘We need very much a name to describe a cultivator of science in general. I should incline to call him a Scientist.’ (Ayoto, 1990). It is our belief that all children are seekers of knowledge and they go about this searching through a process of discovery integrating their senses and cognitive functions.

The arts are multi-disciplinary as children learn the skill sets necessary to master the various arts disciplines of holding a crayon or brush and learning to scribble and then connecting lines and shapes, etc; or holding an wind instrument and figuring out what amount of pressure to use when breathing and blowing into it so sounds can be made; or using their bodies to move through space at different speeds, making different shapes and mastering various planes of movement- from the floor, to walking and jumping into the air, etc. Children are natural multi-disciplinary learners and the value of this understanding was not lost on the ancient Greeks. Plato, in writing about art and philosophy says, “he had knowledge, and he had art; for once the philosopher and the poet lived in one soul; and he created for himself a medium of expression in which both beauty and truth might find room and play”. (Durant, 1961/1926)

Creative Process applies to the arts & science and is one meeting ground. Graham Wallas, (1926) was a political scientist at the University of London. He was one of the first to study the thought processes of poets, artists, scientists and others. In his seminal book ‘The Art of Thought’ he describes the creative process as having four parts. The first three parts he attributes the German physicist Hermann Ludwig von Helmholtz as having first discussed creativity in 1891 and outlined the process as:

Preparation, investigation of the problem

Incubation, not consciously thinking of the problem

Illumination, AHA, the breakthrough experience, the gestalt

Wallas later observed in his research a forth stage and included this in his descriptions of the creative process:

Verification, working it through, the hard work of making something from the idea.

Artistic inquiry and scientific inquiry have many meeting points. The following are a few observations regarding how arts and science meet through experimentation and process.

Arts / Science both have at its’ core an essence of hard work and inquiry, a search for meaning alongside a flirtation with the unknown.

Arts / Science can produce unexpected insights that defy carefully calculated rubrics, designed to predict outcomes.

Artists / Scientists thrive on uncertainty.

In teaching science through the arts, we must take risks and set goals that challenge the status quo, using our expertise as artists and teachers/scientists to illuminate new pathways toward a more just world.

The poet E.E. Cummings (1950) touches upon this spirit of inquiry, wonder and awe in the following excerpt from this poem:

I thank you God for most this amazing day
For the leaping greenly spirits of TREES
And for the blue dream of SKY
And for everything which is natural
Which is infinite
Which is YES

The arts when used in the service of the child are at the core of human development and learning. The child never stops learning through his/her natural, innate inquisitiveness and the medium for experimentation is through ‘play’. Play at its highest form of development is the natural medium from which the child begins and continues their experimentation to make meaning and understand the world around them. Art is about doing, seeing, thinking, feeling, and being in its fullest sense. It is personal and social. It links past with present, culture with existence. Our relationship to art is direct. We grow to know art as we come to experience art through making and viewing, asking questions, posing solutions, searching within the medium itself. The parallels for scientific inquiry and artistic inquiry are closest to the child traversing through elementary school. This is the period where sensory learning is key and slowly becoming integrated with cognitive learning. And this is why it is so critical to allow the child to learn, experiment and discover within their natural developmental stages.

The Prince William Sound Science Center in Arkansas, USA has understood these learning principles and applies kinesthetic learning techniques to teach students complex scientific concepts. The following video link demonstrates a very innovative method for integrating science with movement: https://www.youtube.com/watch?v=0vrf6xXqeuE

Public engagement programs & K-12 educational programs advances scientific literacy by offering programs for people of all ages with opportunities to connect with scientists and experiences to interact with nature, thus creating space for dialog, discussion and interaction among community members. K-12 educational programs use an innovative combination of classroom, hand-on, arts and field activities to inspire life-long passion for science.

Another important link between science, education and the arts is the principle of 'experiential learning.' Many of the great educators throughout time have come to understand that the child must stay connected to their world through experience, play and discovery as they continue their development and learning. This not only fosters the highest forms of quality education but also helps foster the human values that contribute towards healthy society and coexistence. The following pioneering educators are listed here as examples towards an understanding of the importance of integrating experiential learning at the core of education. Each educator went on to develop their own individual core theories and practices but each have a common thread- the child learns best and naturally through play, experimentation and discovery and the arts have always remained an integrative component of these systems:

John Dewey (Dewey, 1980/1934) - American philosopher and educator who coined the famous term: 'Learning by Doing'. The child learns best by direct personal experience.

* Maria Montessori (Montessori, 1974/1917) – First Italian female medical doctor in Italy who went on to develop the Montessori Schools and method. The 'AHA' spontaneous moment of discovery and integration in learning, that comes from play with objects, blocks, beads, etc was critical in her approach.

* Rudolph Steiner (McDermott, 2007) - German philosopher and educator who developed the Waldorf Schools. At the core of elementary school learning is the necessity to allow the student to explore their world through story telling and narrative.

* Paolo Freire (Freire & Faundez, 1989) - Brazilian philosopher and educator who developed his school of 'Critical Pedagogy' while working with the illiterate populations in rural Brazil. At the core of his pedagogy, learning is not confined within school walls, subjective/student knowledge is valuable, learning is an ongoing process, and knowledge/knowing is co-constructing process.

* Reggio Emilia Schools, founder Loris Malaguzzi, Italy (Boyd Cadwell, L.,1997) - based her pre-school philosophy and approach upon the following principles:

Children must have some control over the direction of their learning;

Children must be able to learn through experiences of touching, moving, listening, and observing;

Children have a relationship with other children and with material items in the world that they must be allowed to explore;

Children must have endless ways and opportunities to express themselves, thus developing the term '100 languages'.

Metaphor, Imagery and Analogy

Karen Gallas (Gallas, 1994), in her book 'The Languages of Learning: How children talk, write, dance, draw, and sing their understanding of the world' has come to understand that in order to educate the elementary school student we must first come to understand how they make sense of the world through the use of metaphor, imagery and analogy. She writes, 'I now see, from my own forays into metaphoric thinking about the natural world, that children's thinking reflects a natural ability to express scientific understandings through imagery and analogy and that it is very difficult for most adults to follow that thinking. I also see that though every child thinks deeply about the world, not all children naturally identify their serious musings with the world of science.' p.72

To this end it is the role of the teacher to allow the child to develop their thinking and musings through play, experimentation and the arts. She has come to understand that the questions children ask often reflect a very deep effort to understand their world and that their ability to form theories about difficult questions far surpasses her expectations.

The following is a poem from one of her second graders that expresses this ability to question and formulate deep understanding and perhaps even the evolution of a child's personal theory:

Have you ever been in a sunny field
when the dragonflies buzzzzzz
and the grass turns green?

Have you seen the lake that runs
into a small quiet stream with fish

and the trees that sparkle in the sun?
And the rabbits jump and run free?

But it's all in me.
William, age 7, p.73

It is the teacher's job to build this sense of inquiry with the student and connect that with the wonder and imagination of existence. Our job as educators is not to have children become 'little scientists', but rather to interpret and translate their many languages, through metaphor, imagery and analogy– through the arts and science, integrating sensory with cognitive learning.

Science Discussion/Talks and Science Journals

So how do we approach this inner world of the child and begin to explore and understand this language of metaphor?

Through Talks and Journals children develop ways to make their thinking visible in narrative. While studying science children develop ways to make their thinking and experience of the world visible through the languages of art, dance/kinetic, music/sounds, drama/play. As students gain confidence in expressing their thoughts about difficult ideas, building theories, asking questions through writing, talking and other expressive medium – they begin to value their own role as thinkers and knowers.

Gallas believes that the use of what she calls a Science Journal, is a personal book where your most important thoughts and questions can be recorded. A place to write, sketch, draw about things we are thinking about and observing; questions we have about our world; things we wonder about. What develops from the personal narrative is a story to help children explain their experience.

Students weave stories from personal, intimate thoughts to help think about difficult questions such as:

'Underground is damp. Some insects live underground. I don't know the names of all of them. Do you? I like earthworms. Do you? I like the smells of the ground. Do you? The ground smells damp. In summer the ground is dry, when the soil does not smell. But I still like it. Do you?

Ronit, age 6, p.72

The following is taken from another first grader's journal as she tackles the concept of 'nature.

Nature
If winter stayed forever
trees and flowers would feel bad
because nature made them promise
that each and every year
after winter the trees would have pretty buds
and then they would turn into pretty leaves
and the flowers would have pretty buds
that would beckon.
Amy, age 6, p.56

The journal allows for the child to keep a record of its own thought process and development throughout the school year. It becomes a valuable resource for the child to continue their experimentation and discovery process as they concretize very complex systems through imagery, metaphor and analogy.

Creativity, Flow & Resonance

Next, we turn our attention to some thoughts around the importance of creativity when we are teaching science through the arts. Runco (Runco & Jaeger, 2012) states that creativity is part of what it means to be human. We all have it. "The definition of creativity as construction of personal meaning is also consistent with the notion that creativity is a kind of self-expression and self-actualization." Artists and scientists alike are aware of the importance of the hard work that goes into research and design. The arts are inherently creative because they exist for the purpose of exploring originality and when used in the service of the child, the attributes of the self. Creativity is the energy that unites the arts and science in teaching elementary school children. Regarding widely-accepted definitions of creativity, Bilder & Knudsen (2014) acknowledge that creativity requires "novelty, innovation, disruption on the one hand... but there has to be the imposition of sufficient order to make it of interest, value, or acceptability to the users, whomever they may be." He continues: "Before something goes into a great deal of unpredictability, more complete disorder, there's some boundary at which you cross into a state that others are not going to appreciate." The results of creativity, he suggests, need to resonate strongly with at least one particular community of practice. Robert Bilder is director of UCLA's Tennenbaum Center for the Biology of Creativity and also director of neuropsychological phenotypes consortium. He has studied the biological components of creativity and further identified some universal cognitive components—contributors to creative achievement that have been isolated through neuroscience and cognitive science across studies of broad populations, occasionally with highly creative groups compared with control groups. These include memory, divergent thinking, convergent thinking, and flow.

The so-called magic synthesis that happens when memory, divergent thinking, and convergent thinking work harmoniously together can be enormously pleasurable, and can contribute to " flow" states. According to Bilder, flow "involves a clear balance of [the brain's] stable and flexible regimes. And those states involve high generativity, productivity, flexible memory combination, and the successful inhibition of intrusive habits or fixed ways of thinking, and they enable us to connect more clearly to drive action or perception. Bilder also acknowledges Csikszentmihalyi's (1990/2008) foundational work on flow.

Chand O'Neal (2015) noted that one of the primary findings about the Kennedy Center's 'Changing Education through the Arts' (CETA) program is that arts-integrated classrooms have the potential to bring about "deep satisfaction, or the sense of resonance" for children. Echoing Limb and Stern's explanation of flow, Chand O'Neal discussed the pleasure or enjoyment factor inherent in creativity, and its potential to create freedom from negative self-consciousness and self-critique. She called it "the odd feeling that you belong to this thing, and it belongs to you, that happiness."

Is it possible to allow 'happiness' into our teaching and classrooms and also to foster moments of Flow and Resonance that emerges from deep scientific and arts explorations? Fortunately, we have no choice when we allow the arts to be integrated with the teaching of science because this is what emerges through the creative process. Children learn to respect one another and their teachers as they themselves are being respected and encouraged to dive deeper and deeper into scientific exploration and creative exploration. The process can at times be long and tedious, at times repetitive and challenging but when the child is encouraged to stay the course and stay with the creative process, small moments of wonder and awe emerge, building upon sound pedagogical principles that lead to lessons filled with inquiry, exploration and moments of 'AHA' discovery.

A Case Study: Al Zaharaa Elementary School, Kfar Kassem, Israel

Safuat Taha is the principal and visionary for Al Zaharaa Elementary School in the Arab city of Kfar Kassem in Israel. Together with his first to sixth grade teachers, staff and families in the community he believes that changing the world begins with one child, one family, one school and one village at a time. Each day 600 students study at the school, which is fully integrated through the arts being included in most subjects. There is a strong environmental arts and science arts program where students are encouraged to choose from over 40 classes including: herbal gardening; olive oil cultivation; water conservation; astronomy; meteorology/weather patterns; hydroponics; herbal plants and herbal formula production; study of bird migration patterns. Integration of Arts and Science in the classroom is fundamental to achieving his goal of having every child and family succeed. The school has a holistic approach that fully integrates all of the required classroom curriculum along with the areas of nutrition/cooking, culture/arts, sports/exercise, math and science.

The school has a grove of olive trees maintained by teachers, students and parents. Peeking out from the branches are bird feeders that attract some of the billion birds that fly over Israel every year. The country is located in the middle of the flight path of the annual bird Africa-Europe migration and is second in the world in terms of numbers of migrating birds. As part of a school-wide science project, students create bird feeders that attract many different birds throughout the year. They wait in a bird blind to photograph and document the birds, which they later identify and record.

Olive Tree Garden with bird feeders attached & doves

Student decorated bird feeder made from recyclable plastic containers

The school has one of the country's most advanced educational water recycling programs and rainwater is collected in a series of seven tanks that are used to operate the school's toilets. While similar programs exist at some other schools in Israel, the beautiful artwork that decorates the tanks is unique.

Water recycling tanks maintained and operated by students and staff

Making art from recyclable materials

Astronomy Room - Planetarium

Taha stresses the importance of making the world around us a source of curiosity, pleasure and pride for his students. Nowhere is this more evident than in the school's astronomy room. Painted black like deep space, the ceiling is covered with a representation of the night sky that comes alive when you turn off the lights. The room is filled with student reports, informative posters, planetary models, a sophisticated telescope and a person-sized replica of the space shuttle. It evokes wonder, stimulation and a passionate desire to learn about the world around us, in everyone who walks in.
Similarly, the school's meteorological station attracts pupils to engage creatively with their weather and the pursuit of scientific inquiry. Groups of students use instruments to measure changes in the environment and to understand how their local conditions affect and are affected by the global ecology.

Meteorological Station

Values & Family Involvement
Most important to Taha is instilling positive values in his students. In deciding how to divide the short six hours a day that he has with his pupils he prioritizes giving them good models of behavior that will serve them for the rest of their lives and he uses the arts to reinforce these messages. One program based on the zodiac

assigns each month with a specific ethical trait which the students research, represent and embody. One way they internalize the values is by painting a mural of the month's zodiac sign together with a text describing how the value is manifest.

Values based arts/science program based on monthly Zodiac signs

Taha understands that an important and perhaps essential step in instilling values like this one is through ensuring parental involvement. He instructs his teachers to give assignments to the students that require the participation of family members so as to better integrate them into their children's experience. A typical assignment might involve having the pupils work together with their parents creating a work of art on the subject of a certain value. They would then write a composition based on their artwork, and in this way, improve their written expression. Then, they would give a class presentation about their work and their composition to an audience of students and parents, and in so doing, work on their oral expression skills as well as further involving the entire family.

The transformation that Taha has created in the Al Zaharaa elementary school is significant. By all metrics—academic performance, national awards, cooperation with external institutions and individuals, etc.—his recipe for integrating the arts, science and values into education seems to be working. He hopes to magnify the effects of the personal training he gives and organizes for his faculty by requiring them to serve as mentors for other teachers and his innovative and creative methods are beginning to be copied by other schools in the Arab sector, as well as around the country. It would seem that educators around the world would have many lessons to learn from Principal Safuat Taha of the Al Zaharaa elementary school in Kfar Kassem.

Conclusion

Children experience wonder and awe naturally as they explore their world and attempt to find meaning and learn. This natural state is important to cultivate and science studies is an excellent match to allow children to continue this exploration and discovery process. This is not a curriculum goal but it is part of the beauty and natural inquisitiveness that scientific inquiry holds. Wonder and imagination are the prerogatives of childhood development that later becomes an essential instrument in the work of the poet, the artist, the creative thinker and also the scientist. By recognizing the importance of wonder and imagination in building the child's understanding of the world we can access a wealth of sensory and cognitive data and concepts that express scientific theories and principles. Integrating the arts into teaching science allows the child to learn using all of their sensibilities and cognitive capacities, including imagination, imagery, metaphor and analogy. The world of the imagination is a place where deep knowledge is obtained through experimentation, and 'hands on' creative action. For children, who live in the universe of the imagination, who are still filled with wonder and awe, finding ways to study the world that incorporate these transcendent modes of being and thinking becomes a necessity.

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Not Falling into the Trap of Dichotomizing Formal and Informal Science Education

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Introduction

Informal and nonformal learning, informal settings, outdoor learning, and free-choice learning environments are all common terms used to describe the variety of learning opportunities that are provided in out-of-school settings. Each of these terms has multiple meanings, justifications for use and antagonisms. in the policy statement of the Informal Science Ad Hoc Committee, informal science learning was defined as "science learning that occurs outside the traditional, formal schooling" (Dierking et al. 2003 , p. 108). However, this term is criticized as limiting other forms of learning that occur in everyday contexts as a result of the intrinsic motivation in free-choice situations and that are lifelong experiences (Tal, 2012). In this chapter, as in previous publications, I and others argue that attempts to dichotomize formal and informal science education are dated and counterproductive (Dillon, 2016; Hofstein & Rosenfeld, 1996; Tal et al., 2016). Our studies have shown that structured teaching can occur in informal learning environments regardless of the opportunity they offer for free-choice and explorative learning (Lavie Alon & Tal, 2017; Morag & Tal, 2012; Tal, Lavie Alon & Morag, 2014). On the other hand, we have documented exemplary practices of outdoor educators who thoughtfully use the special characteristics of the outdoor environment to promote meaningful learning (Tal et al., 2014; Lavie Alon & Tal, 2017).

There is much literature on the benefits of outdoor learning, summarized, for example, in an entire section of the Second International Handbook of Science Education (Fraser, Tobbin & McRobbie, 2012). This literature provides evidence for student learning, good field trip practices and the value of good preparation, and the long-term impacts of fieldwork (Dillon, Rickinson, Teamey, Morris, Choi, Sanders & Benefield, 2006). However, there are barriers to outdoor learning, such as concerns about student health and safety, teachers' lack of confidence and even reluctance to teach in the outdoors, competing agendas of schools that are under pressure to do better in national and international tests, and so forth (Tal, 2012; Ballantyne & Packer, 2009; Bixler, Carlisle, Hammit, & Floyd, 1994; Dillon et al., 2006). In several studies carried out in museums, teachers' function was addressed by the researchers who pointed to the teachers' key role in the success of the field trip (DeWitt & Hohenstein, 2010; DeWitt & Osborne, 2007; DeWitt & Storksdieck, 2008), but research also points to inadequate involvement of teachers when an informal educator is involved (Tal & Steiner, 2006; Cox-Petersen, Marsh, Kisiel, & Melber, 2003).

Studies focusing on the teacher's role in museum visits in which a local, professional guide led the activity, revealed a dysfunction of teachers in those field trips: they did not plan the field trip themselves, they were not aware of the program and its purpose, they were not involved in choosing the learning activities and they demonstrated a passive behavior pattern (Faria & Chagas, 2013; Griffin, 2004; Tal, Bamberger & Morag, 2005; Tal & Steiner, 2006). Cox-Petersen et al. (2003), for example, showed that although after the field trips teachers had many pedagogical suggestions, overall 67% of the teachers they studied expressed their satisfaction with the visit.

In our group's previous work, we identified several patterns of teacher function in outdoor environments, as well as in a science center (Tal, 2001; Tal & Steiner, 2006). We pointed to a range between "passive" teachers, ones that "follow the school tradition", and finally – "involved" teachers, who are actively engaged in the entire field trip from its preparation and till its wrap-up in school. We found that quite often teachers do not take the opportunity to be more active. Other scholars pointed to similar patterns. Tran (2007), for example, who examined interactions between teachers and museum educators, found that there is a need to clarify the roles and responsibilities of classroom teachers and museum educators in museum settings, so that each one will know what is expected from the other during field trips. Faria and Chagas (2013), who studied aquarium visits in Portugal, found that even when there is an opportunity to have non-guided visits, teachers prefer the guided ones and then exhibit passive behavior.

In a study of field trips to a science center, Tal & Steiner (2006) found that most of the elementary school teachers were satisfied with having only technical-organizational contact with the museum, but secondary school teachers were more interested in the program, the science content, and the pedagogy offered by the museum educators. They found as well that 21% of the teachers demonstrated passive behavior, 57% were identified as "following the school tradition", which means that they did what was necessary in terms of helping the guide – mainly with technicalities, and only 21% were involved in explaining, asking questions and directing their students. In another study of 30 teachers visiting four natural history museums, no active involvement of the teachers was identified (Tal et al., 2005). Being aware of the relationship between the two leading adult agents – the teacher and the guide – who represent different practices, we refer to the idea of communities of practice, which is widely discussed in the research literature in general, and in the literature of out-of-school learning in particular.

To understand the differences between teachers and informal educators, Kisiel (2010, 2014) suggested using the communities of practice framework. He argued that teachers and field trip guides belong to two different communities of practice, who speak different languages, have different beliefs and sometimes different purposes. School teachers share a domain of interest which defines their identity and distinguishes them from other people. They build relationships that enable them to learn from each other and share their practice of teaching (Pedretti & Bellomo, 2013). Field guides make up a different community of practice which differs from the teachers' community of practice, in the same way formal education differs from informal education. A study of environmental educators from state and local parks in the United States recognized them as a community of practice, as they shared a set of core teaching beliefs and practices of non-formal environmental education. Their practice puts the emphasis on hands-on learning, acknowledging the differences between individual students, and the importance of ensuring a sense of comfort and safety for the student. The researchers described the informal educators as learner-centered, responsive to student needs, ill-structured, and as practitioners who often maintain non-formal relationships with the students. They also suggested that the informal environment itself shapes the characteristics of the community, and that different environments could influence the kind of communities of practice one can identify (Taylor & Caldarelli, 2004).

An extended description of characteristics of formal and informal sectors and their contribution to science education, concludes with the call for collaboration and communication between the two (Stocklmayer, Rennie & Gilbert, 2010). Nevertheless, research on formal and informal science education collaborations has revealed that fruitful collaborations take significant time and energy, but yield valuable outcomes for both students and institutions (Cook & Weiland, 2013). In the article "We Need To Talk", the authors suggest particular questions for the preparation and planning of a museum field trip that will improve collaboration and could lead to effective museum learning outcomes. Wright-Maley, Grenier & Marcus (2013), and DeWitt & Osborne (2007) used the framework of Cultural Historical Activity Theory (CHAT) to enhance the involvement of teachers in the museum visit that they enact themselves. An interesting discussion between a high school teacher, an administrator at a natural history museum, and a researcher and educator, was conducted on the collaboration between schools and informal science institutions and their role in creating an authentic, collaborative science-learning experience (Adams, Gupta, DeFelice, 2012). The researchers mentioned a few key factors that contributed to building a successful collaboration: shared goals, shared language, and awareness of each other's culture and perspectives. They concluded that much effort should be invested in creating meaningful collaborations to support better learning. Jim Kisiel's study of the collaboration between a school and an aquarium (2010) examined the development of the collaboration in order to document challenges and keys to a successful relationship. He found that participants from both communities increased the overlap between the two communities of practice due to the knowledge the school teachers and the aquarium instructors acquired from each other and their shared responsibility for the students' outcomes. As they became more aware of the difference in each other's educational practice, they made adjustments that increased the overlap between the communities.

Most studies of collaboration between formal and informal educators' communities look at the relationships between teachers and informal organizations and institutions. Fewer engage in direct relations between teachers and guides, especially in museums or in classrooms. Cook & Weiland (2013) studied an environmental education partnership between a teacher and a non-formal educator who was the education director for a local solid waste management district. They revealed a difference in their perceptions of goals and roles; However, although the informal educator had no pedagogical training, she was very creative and based on their observations, the researchers concluded that formal and non-formal educators can support another's one goals through systematic collaboration. Another study of Weiland and Akerson (2013) examined partnership in a classroom setting, and explored student outcomes as a result of the partnership. They examined the relationship by classifying the partnerships into three distinct types: cooperation, coordination, and collaboration. The informal educator provided the students expert content with resources that are not available to them, and used unfamiliar teaching methods. The classroom teacher's role included classroom management, making connections to classroom activities and curricula, and clarifying concepts. This relationship was classified by Weiland and Akerson as coordination which requires moderate commitment, risk, negotiation, and involvement. This relationship is appropriate for continuous educational programs, but is less applicable to a single field trip event. Moreover, this study refers to collaboration in class or in man-made settings, while we are studying single events in outdoor natural environments. Finally, we studied teachers and outdoor educators in field trips to nature parks and found a variety of relationship patterns including teachers who were actively involved in the field trip program and enactment and others who demonstrated limited involvement and interest (Lavie Alon & Tal, 2017; Tal et al., 2014). Teachers and informal educators practices can either create gaps in the ways learning is seen and in the way they communicate with each other and with students. Another aspect worth discussing is how we view student learning outcomes in formal and informal environments.

Learning outcomes

Commonly, student learning outcomes which are studied worldwide, are examined in three dimensions: cognitive (knowledge, concepts, processes, skills), affective (beliefs, values, attitudes) and behavioral (Weiler & Ham, 2010). Already, Bamberger & Tal (2008) aimed at identifying multiple outcomes of the museum visit. They also aimed at identifying an effective means of documenting these outcomes (Bamberger & Tal, 2009), and concluded that given the diverse learning outcomes, no one instrument was found good enough to document learning outcomes. The NRC (2009) report on informal learning presents six strands for science learning in informal settings. The strands include developing an interest and motivation in science (strand 1); promoting an understanding of scientific phenomena and creating scientific knowledge (strand 2); experiencing and practicing scientific skills (strand 3); understanding the nature of science (strand 4); acquiring skills that will enable scientific debate (strand 5) and developing.
addthe willingness to be a scientist (strand 6). These goals are discussed in the report, mainly in the context of designed environments which are carefully crafted and structured and are not necessarily achievable in natural environments (Tal et al., 2014). Another perspective of learning outcomes that comes from environmental education, focuses on increasing knowledge about the environment, influencing the attitudes and behavior toward the environment and developing skills and tools that enable environmental action (Nundy, 1999). Accordingly, in this study, we documented self-reported learning outcomes in three domains: cognitive, affective, and behavioral.

Most studies investigated learning outcomes through structured questionnaires given before and after the educational activities (Lavie Alon & Tal, 2015). It is agreed that measurement of learning outcomes in outdoor environments is difficult for several reasons: lack of a systematic curriculum, lack of orderly processes of assessment, and the complexity of the outcomes, including attitudes and behavior in addition to knowledge. Many studies in the field point to insufficient research on learning outcomes in the context of out-of-school learning (Tal, 2012; Ballantyne & Packer, 2005; DeWitt & Storksdieck, 2008; Munro, Morrison & Hughes, 2008). Given that, Lavie Alon & Tal (2017) investigated teachers' involvement in field trips and its relationship with students' self-reported outcomes. In studying the relationships between teacher involvement and student outcomes in field trips to the outdoors, they found that greater teacher involvement has contributed to higher self-reported learning outcomes of the students. Yet, another gap between formal and informal science education has to do with how to assess directly learning outcomes. One way to address the previous two challenges of collaboration and of identifying and assessing learning outcomes is through direct work with teachers in informal environments such as the outdoors.

Teaching Inquiry-based Learning in the Outdoors

In studies held in the USA and in Israel, we intended to work together with teachers to enhance their capacity to teach inquiry in the outdoors. In the US, an Institute of Science Education and a Research Biological Station from a large midwestern university collaborated in developing the "Taking Science to the Outdoors" (TSO) program that intends to do the following: (a) establishing long term relationships with a group of teachers, and supporting them throughout developing outdoor-inquiry learning units for their schools; (b) using Next Generation Science Standards (NGSS) (Lead States, 2013) as guidelines for the development of the school-based learning units; and (c) using technology to teach inquiry-based science in the outdoors. During four-year experience with TSO, we have followed the teachers during a 4-5-day program, and then subsequently through activity on the program website (such as posting reflections and lessons online), follow-up workshops and webinars, and other forms of continuous participation in science learning and teaching. I will now focus on some lessons learned from our experiences with four cohorts of teachers between 2014-2017.

The 4-5-day TSO-Professional Development (PD) took place at a research biological station of the university, which is in close proximity to both large urban and rural education districts. The main focus of TSO was on how teachers can use available resources such as their schoolyard and other nearby city parks or woods to teach science aligned with NGSS in the outdoors. The PD included outdoor observations and investigations connected to specific NGSS performance expectations, and classroom discussions on how to modify such experiences to diverse grades, school needs and resources. In small groups the teachers translated these experiences to construct outdoor lesson plans aligned with performance expectations they identified and used the outdoor teaching pedagogical principles we highlighted such as learning with hands, heads and hearts (Sipos et al., 2008), reducing the Novelty Space (Orion, 1993) and encouraging free-choice learning in the outdoors (Falk, 2001). We used as well a battery of learning technologies to support collaborative learning, developing outdoor science lesson plans, and developing a long-term community of practitioners committed to teaching authentic science aligned with NGSS.

About 70 elementary teachers have attended TSO during four summers. Most teachers have come from nearby rural and urban school districts. Most teachers attended as part of a team of 2-4 teachers from a school. Their teaching experience has varied from 2 to 20 years. The vast majority teach all subjects including science with no particular background in science. In documents they submitted to enroll in the program, they all expressed interest and excitement to learn about using the outdoors for teaching science.

TSO program allowed us to work with local teachers on using authentic outdoor environments toward teaching science in more productive ways. Using NGSS and a battery of pedagogical principles, through active learning, the teachers experienced outdoor learning and were engaged in developing their own lesson plans aligned with NGSS. They overcame their novelty and gained more confidence. Some of the teachers have enrolled in other professional development opportunities related to outdoor science education. TSO was the trigger for more elementary teachers to join this community and create their own group. TSO offers a bridging approach between formal and informal science education, which allows exposing more students from underserved communities to outdoor learning, by simply working with their teachers to help them use local resources to teach authentic science, aligned with NGSS. TSO enabled us to work on and develop a productive, compelling and responsive science teaching in nearby outdoor environments. We see the teachers as the main agents rather than as brokers in this process and we showed that good science education can occur in the schoolyard, park or a city trail, and propose that elementary teachers use all the resources available to promote authentic and effective science teaching (Tal et al., 2018).

In Israel, as in many other countries, teachers commonly refrain from taking their students out because of personal challenges, insufficient training, overloaded curriculum, testing routines and school bureaucracy. Moreover, often teachers refrain from viewing scientific practices in a way that allows investigating the real world outside the classroom. In an attempt to help Israeli pre- and in-service teachers cope with these challenges, we introduced teachers to different genres of investigation – all occurring in the outdoors: archeological, social and ecological (Tal, Aviam, Levin Peled & Lavie Alon, 2016). We used as well, an online environment, which we developed to support the teachers enhanced collaboration and meaningful discussions.

We believed that the school walls can be a metaphor for artificial boundaries between learning and fun, between being active and passive and between fields of knowledge or well-defined disciplines and interdisciplinary and systems approach. We assumed that taking the teachers away from their known teaching environment and comfort zone could help them find new avenues for teaching, in general, and to inquiry-based teaching, in particular.

Three inquiry activities carried out in the outdoors were the focus of this teacher professional development program. The activities were in the fields of ecology (the study of the natural world and relationships with human impacts); sociology (the study of human societies); and archeology (the study of ancient cultures' material world). We carried out all the activities in one particular area to develop a more profound understanding of the relationship between the physical, the historical and the social layers of a system. Our main goals were to (a) expand and deepen the teachers views of inquiry and inquiry-based teaching; and (b) encourage teachers to use the outdoor learning environment, not only to teach about things and/or to develop national values, but, moreover, to make them enjoy learning and teaching in the outdoors and to develop teaching for engagement and for understanding complexity. One more reason for learning in the outdoors, especially for science teachers, was to help them depart from the image of inquiry learning as experimentation. We used as well a variety of technological tools to enhance collaborative inquiry learning and reflection. Throughout the program, the teachers worked mainly in small groups, and sometimes individually, in the preparation stages of the investigations.

We view technology as a driving force that enables collaborative learning in various learning environments and especially in inquiry learning. Thus, we designed a simple website to support the program; a website that allowed sharing and learning from each other, which could be built by teachers as well. The website was designed to support teachers in their efforts to teach through inquiry by providing a whole battery of scaffolds. We used available mobile apps for the field work – ones that every teacher can download for free. Altogether, we worked with 10 groups of 3-4 secondary school science teachers.

Eliminating the Formal and Informal Gap

The distinction between formal and informal aspects of education is difficult. This position is supported by research that has found that the distinction is worthless, as some school-based activities can be regarded as informal, while often, activities in museums are formal and lack flexibility (Dillon, 2016; Hofstein & Rosenfeld, 1996). It is easier to argue that group picnics, sitting together in a circle and sharing food, are all informal, or that a structured preparation activity, guided by instructions given in a website, is formal. However, most of the field activities are difficult to label. For example, a group of teachers who began their social investigation in a minority village following a plan they prepared prior to the field investigation, were invited to a house by a woman who saw them wandering around. They then sat with few women and listened to their stories. This group did not complete the planned data collection, yet summarized the day as a great learning experience. Eventually, due to this experience, the group shifted its research to focus to stories told by the minority women. Another example is a pre-arranged meeting with the representatives of two villages in the sociological investigation. Although they were pre-planned, each of these meetings was then developed differently, according to the teachers' interests and the representatives' stories and emphases. A third example of the blurring between formal and informal learning was in the archeological investigation, where the teachers met an archeological delegation from a US university. A few teachers took the opportunity to talk with the American professor and his father (an archeologist, too) while their peers did the planned activity. This unplanned side activity ended with the teachers enthusiastically reporting to the others about what they had learned from the conversation with the American researchers.

Conclusion

In the few examples provided in this chapter, I aimed at demonstrating how worthless the distinction between formal and informal science education is. I wish to argue that there is good and poor pedagogy, and that both can be observed in schools and classrooms and in museums and nature parks. The physical environment or whether it is in school or out-of-school does not make the difference. Rather, it's the effort put into making the learning meaningful. In order to use both formal and informal learning productively, teachers and informal educators should develop a new discourse that overcomes dichotomizing learning environments and such that focuses on how to make learning meaningful in and across all environments. I demonstrated how both in the US and in Israel, teachers who were involved in inquiry learning in the outdoors have developed deeper understanding on how to use informal environments to support their regular teaching. Those teachers will feel more comfortable to take an active role in their students' learning in informal environments, even when those are facilitated by informal educators.

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Phosphorus – From the Sustainable Development Goals Towards Transformative Non-Formal and Formal Education

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Abstract

The element phosphorus and phosphates as chemical compounds are rarely treated as self-standing topics in most secondary chemistry curricula, even though they play a central role in the current debate about the Sustainable Development Goals (SDGs) issued by the United Nations, as well as in the concepts of planetary boundaries and critical raw materials. In this article, relevance and importance of learning about phosphorus/ phosphates to society are justified. Also, how the topic can be integrated in a transdisciplinary teaching approach is demonstrated based on practical work and in modern ICT via formal and non-formal learning experiences.

Keywords: chemistry education, education for sustainable development (ESD), planetary boundaries, phosphate recovery, ICT in science education, non-formal learning

Introduction

Phosphorus, the light-bearing element, was discovered around 1670 by Henning Brand by evaporating urine while searching for the Philosopher's Stone. This story is known to most chemistry teachers and may work as an anecdote in teaching to introduce the element phosphorus. Phosphorus and phosphate are, however, not typical topics in teaching and learning chemistry in secondary schools or in general chemistry at the undergraduate level. They might be introduced briefly, but the current societal discussion on phosphate supply and recovery are generally not included.

Phosphorus and phosphates are increasingly recognized in the political debate over sustainability and transforming the world for a sustainable future. Considering phosphates' importance as a vital component in fertilizers and the world's growing population, it is essential to include phosphate in any debate over our future way of life on earth.

In this chapter, we introduce different aspects of the current discussion on phosphates and how this discussion is connected to the Sustainable Development Goals (SDGs), the concept of the planetary boundaries, and the recognition of phosphate and phosphate rock as critical raw materials.

On Sustainable Development Goals, Planetary Boundaries and Critical Raw Materials

Phosphorus/phosphate in the Sustainable Development Goals

The ever-changing interpretation of the concept of sustainability, as well as its history, have already been described many times by researchers including Burmeister, Rauch and Eilks (2012). Sustainability or sustainable development aims to ensure that our way of life today does not restrict the future generations' way of life (WCED, 1987). Hereby, education has a unique role in imparting concepts, pointing out ways, and stimulating action without indoctrinating future citizens. Since the 1990s, the concept has generally been characterized by three areas of sustainability: ecological, economic and societal sustainability (UNCED, 1992).

In 2015, the United Nations issued the Agenda 2030: Transforming Our World (UN, 2015). With this awareness and realization on the importance of creating a sustainable future, the international community agreed that current problems, such as climate change, can only be solved with a global effort. Key issues include protecting the dignity of the human and the planet, promoting prosperity and peace for all, and building global partnerships. These and others were summed up in 17 Sustainable Development Goals (SDGs). Having high-quality education, one of the SDGs, is expected to ensure that "all learners acquire knowledge and skills needed to promote sustainable development" by 2030 (UN, 2015; p. 21). Another SDG known as "Zero Hunger" aims to end malnutrition by 2030, remove residues, stop hunger, and double agricultural production (BMZ, 2018). This increase of agricultural production is linked to the growing world population, for which adequate food and its fair distribution should

be guaranteed.
In 2016, Rockström and Sukhdev (2016) attempted to combine the SDGs with the topic of food, resultinh in the Wedding Cake model shown in Fig. 1. Life below water, life on land, clean drinking water and sanitation, and climate action are the basis for all other goals, including zero hunger. Sufficient availability and responsible use of fertilizers is central to the production of food, for which a sufficient and equitable phosphate supply is indispensable.

Planetary boundaries and phosphorus/phosphate

A glimpse at the media draws a picture that illustrates mankind´s growing influence in our world. Among all, ozone depletion and its connection to chlorofluorocarbons (CFCs) are important to recall. Today, issues such as carbon dioxide emissions, eutrophication, and decreasing biodiversity show increasing impact of humankind on the planet. This discussion went so far that scientists have been discussing a new epoch, Anthropocene, the age of mankind, for almost 20 years (Crutzen & Stoermer, 2000; Maslin & Lewis, 2015).

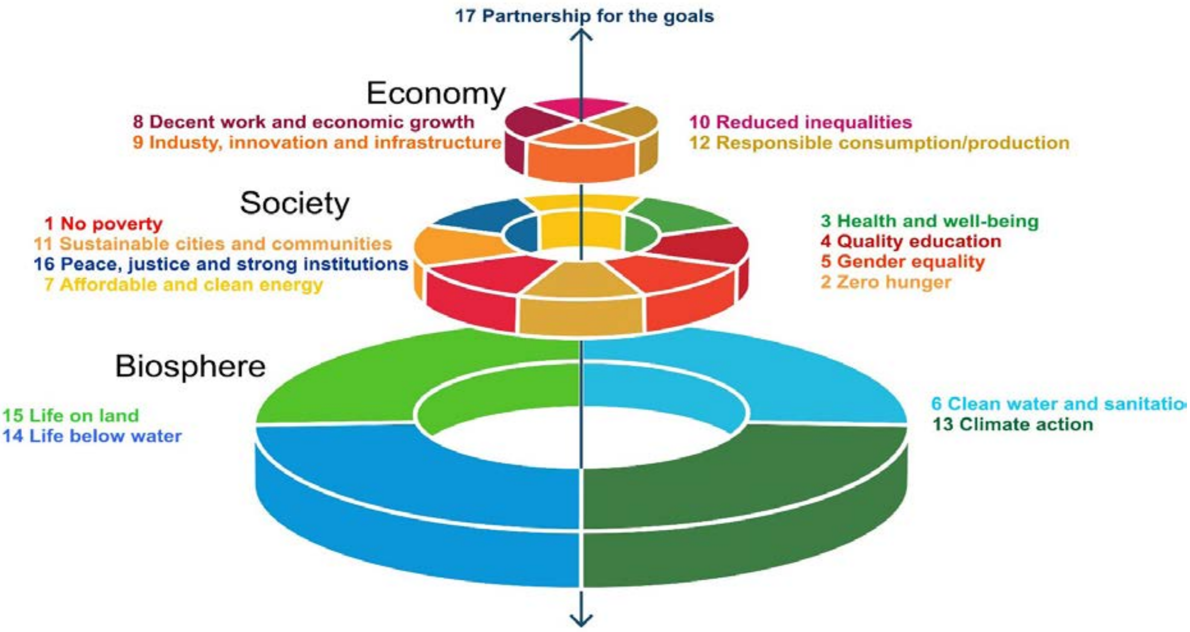

Fig. 1: Sustainable Development Goals (SDGs) in the Wedding Cake Model (Rockström & Sukhdev, 2016)

At the heart of this discussion is the extent to which mankind can exploit the earth without causing irreversible damage. To understand these limits, the concept of planetary boundaries, which tries to define a safe corridor for mankind in the world, was developed (Steffen et al., 2015). Nine planetary boundaries, including climate change and ozone depletion, (Figure 2) have been defined. The most discussed planetary boundary today might be limiting climate change at the 2°C target. Another boundary concern includes biochemical flows that focus on nitrogen and phosphorus. For each boundary, characteristic values should be determined to describe whenever a boundary is crossed.
In Figure 2, the safe planetary boundaries are marked in the second circle from the center ending a green space. In this green space, life on earth should be in a safe operating situation. Once this limit is exceeded, a risk of irreversible damage for the environment and the earth is expected more likely to happen. This zone is represented by the next two circles, which are marked in yellow. If mankind reaches the red area beyond circle four, highly critical changes that can have spontaneous consequences for humans and the environment are more likely to take place. Question marks indicate that key values have not yet been defined for each of the planetary boundaries; e.g., key values on the entry of novel entities as chemical pollution into the environment are still missing.
The parameters of almost all planetary boundaries that were already defined have deteriorated in recent decades, with the exception of ozone depletion. This positive change gives hope because it seems that some influences of humankind on the environment can potentially be reversed. In 1990, ozone depletion was in the red zone. The citizens of the world acted responsibly and agreed on an action plan laid out with the Montreal protocol, which banned any further mass production and uses of CFCs. Consequently, the stratospheric ozone concentration started to recover.

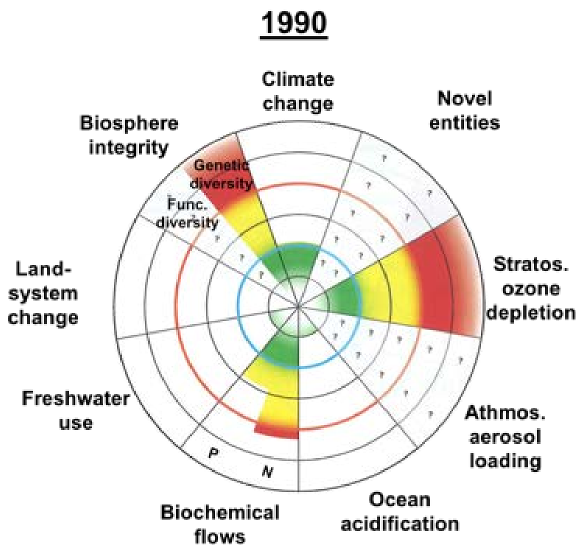

Fig. 2: Planetary boundaries (Müller & Niebert 2017)

While the trend in the stratospheric ozone is promising, the forecasts for the nitrogen and phosphorus biochemical flows have worsened. The comparison of 2015 data to those gathered in 1990s indicated that the issue has reached more critical levels. For phosphorus, the measurable parameters are the global phosphorus flux into oceans and the regional phosphorus flow via fertilizer into the soil. In 2015, both parameters were considered to have about twice the value of the suggested planetary boundary. The use of fertilizers is, however, likely to be inevitable given the demand for higher agricultural production for a growing world population. Therefore, the questions of recovery and recycling of phosphates from wastewater and agriculture have become more important to be discussed.

Critical raw materials and phosphorus/phosphate

Since 2014, phosphate rock has been part of a list of critical raw materials published by the European Commission (EC, 2017). Critical raw materials are characterized by two criteria: economic importance and a supply risk. In the 2017 version of the list, 27 raw materials were identified, whereby economic importance and criticality are applied differently to each critical raw material (Figure 3).

The economic importance of phosphates stems from their major use in fertilizers. They are an indispensable component for any kind of fertilizer. Phosphates are essential for successful plant growth, and cannot be substituted. The potential supply risk is primarily due to the location of known natural phosphate rock deposits. 75% of the worlds' reserves are in only one country: Morocco. Since 2017, white phosphorus, produced from phosphate, has been recognized as a critical raw material. White phosphorus is essential for the chemical industry, but it is produced in only four countries, namely China, Vietnam, Kasakhstan and the USA.

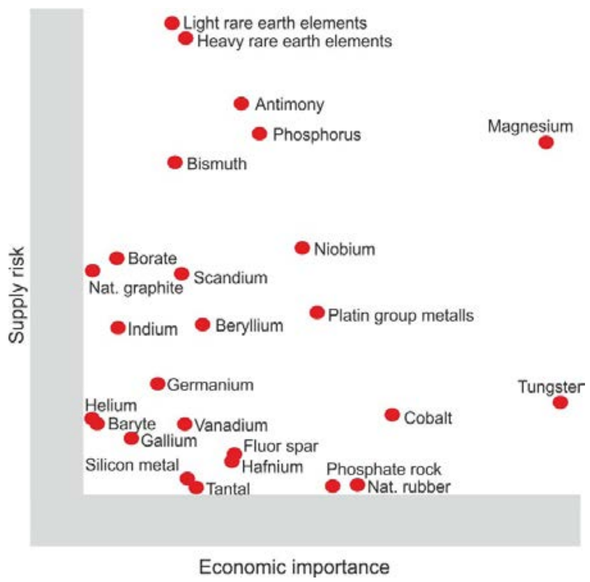

Fig. 3: Critical raw materials 2017 (EC, 2017)

In 2009, publications (e.g., Cordell, Drangert & White, 2009) claimed that phosphate reserves are being depleted.. This is unlikely according to current forecasts. Considering the steadily increasing annual mining rates in the last decades, it is foreseen that the remaining phosphate reserves could last about 300 years (Killiches, 2013). Nevertheless, there are good reasons for closing the phosphate cycle through recycling. The

ProcessNet Specialist Group Raw Materials (2017) suggests the following reasons:

- Securing the raw material supply; avoiding dependencies on supplier countries; having no possibility of substitution
- Preventive environmental protection to limit eutrophication; limiting uncontrolled phosphate distribution via sewage and sewage sludge; savings of landfill space; controlled re-distribution of phosphate into the environment
- Avoiding increasing release of heavy metals in future phosphate degradation, especially cadmium and uranium
- Coming up with modified legal regulations stating that phosphate must be recovered (e.g., a German law was passed in 2015 for full recovery by 2029)

Cordell and White (2011) indicate that quality and accessibility to phosphates will decrease over the next years, which will cause prices to rise. This change will mainly affect small farmers and subsistence economies, who are unable to refinance rapid price increases as seen in 2008. Back then, the price of phosphate rock rose from $50/t to around $425/t over a short term (Killiches, 2013). Food prices are generally closely correlated with those of fertilizers, and thus of phosphate. Dramatic increases on phosphate prices could hinder the implementation of SDG 2 “Zero Hunger”.

Recovery of phosphate is considered to be so important to the European Union that a German phosphorus platform has been established to discuss concerns about the use of phosphates and promoting innovation for phosphate recovery (deutsche-phosphor-plattform.de).

Phosphate Resources, Exploitation, Use, and Recovery

Phosphorus and phosphates are topics that open up many avenues for discussion among different subjects, even beyond the sciences. We will briefly point out some transdisciplinary issues, which can easily be identified in subjects like geography, economics, political science, or history.

Phosphate resources: The cases of Nauru and Morocco

The case of Nauru may seem unbelievable but is a true story, which sounds more like a parable. Nauru is a small island about 3000 km northeast of Australia. About 10,000 people lived on this island, which became independent from Australia in 1968. By that time, Nauru was well known for guano. Guano is bird excrement that accumulated on the island over a long period of time and contains a large amount of phosphate. As a result of guano exports, Nauru became the richest land in the world in relation to its size. The local phosphate rock, Nauruit, was even named after the island. The residents of Nauru started travelling all around the world. They drove expensive cars on the small island, which has only a few kilometers of roads. It was life in the lap of luxury. But, like every parable, there was a dark side coming. The guano ran out to export. With the depletion of phosphate, Nauru ran out of money. Had the government invested the money wisely in other businesses and production, life in Nauru would probably still be luxurious today. Nowadays, due to the malnutrition of the inhabitants of Nauru that started in the rich years, the population is suffering from a high diabetes and obesity rate (The Economist, 2001). Nauru can serve as an example of bad governance in politics

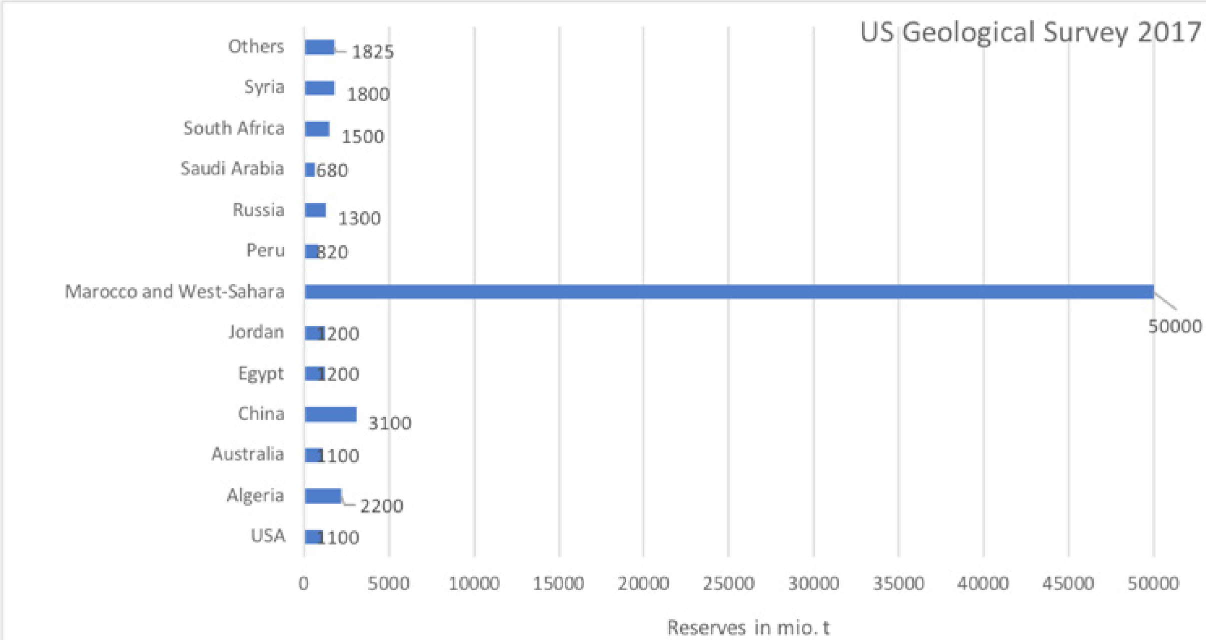

Fig. 4: Phosphate reserves worldwide (USGS, 2017)

and economic education.
Today, Morocco is the phosphate country. It is not a rich country, but it possesses about three quarters of the world's natural phosphate rock reserves (Figure 4). Other major miners such as the USA and China do not export much of their phosphates, instead consuming their own reserves. The Office Chérifien des Phosphates (OCP), which is owned by the state of Morocco, is responsible for mining and processing phosphates in Morocco. According to the media, the working conditions are not at an acceptable level (White, 2015), and it is not clear how much of the phosphate money is invested in improving the working conditions and a sustainable future for the population. If phosphate reserves in other countries are exhausted, Morocco could obtain a monopoly. It is already the most important phosphate supplier for all of Europe. Morocco is, however, located in North Africa, a region that has been shaken by unexpected political instability in recent years. Had this instability also spread to Morocco, Europe might have fallen into a supply crisis. Aside this economic and geo-strategic aspects, phosphate exploitation in Morocco also has political dimensions. There is still a conflict about the status of large parts of the former Western Sahara region (UN, 2018), which were proclaimed by Morocco as part of its territory in the 1980s. In the corresponding former Western Sahara region are parts of the phosphate deposits that are exploited by the OCP.

Who is consuming phosphate?
Europe and the Soviet Union were the dominant importers of the phosphate market until the late 1980s. Today, the phosphate level in both regions is high and the demand for phosphate fertilizers has declined. Other countries are now consuming more phosphate fertilizers. Of the 70% of the world reserves are consumed by four countries the USA, China, India and Brazil. While the USA and China are self-supporters, India is the largest importer of phosphates worldwide.
The irresponsible use of phosphates can also lead to environmental problems. For example, China has a massive problem with over-fertilization, many lakes are considered to be eutrophic (Le, Zha, Li, Sun, Lu & Yin, 2010). At the same time, however, the examples of China, India and Brazil show how intensive use of fertilizers can increase agricultural production (AEEP, 2018).
Africa, the continent with the highest reserves of phosphate rock and the fastest growing population, consumes just 2.5% of phosphate fertilizers (Killiches, 2013). Making the supply of phosphate more equitable, especially in Africa, is probably a key part of achieving SDG 2 "Zero Hunger". Thus, the problem of phosphate is also an issue of global justice.

Recycling
One way to mitigate many potential problems in the supply and use of phosphates is to recycle them. Wastewater contains noteworthy amounts of phosphates. One reason for this is human excrement. Thus, products of wastewater treatment (sewage, sewage sludge or sludge ash) can provide a resource for phosphate recovery.
Sewage sludge is a complex mixture that contains a great deal of organic carbon, but also remnants such as drugs or paints, which are separated during the cleaning process in the sewage treatment plant. At this point, phosphate can also be recovered.
All current phosphate recovery processes from wastewater consist of the following steps:

- Lowering the pH to below 5.5 to remove phosphate from the sewage sludge
- Separation of solid and liquid phase – continuing with the liquid phase
- Precipitation of phosphate by adding a precipitant and increasing pH above 9
- Separation of solid and liquid phase - the solid phase represents the product
- Product processing

Currently, there is no process in the market that is able to recycle phosphates in large quantities at a profitable price. The implementation of appropriate procedures has just begun. The Deutsche Phosphorplattform (2018) provides online fact sheets for many processes, which are objective of current research. With progress in the technology, corresponding technologies might become more efficient and profitable.

Phosphate Recovery in Teaching
The topic of phosphate offers manifold transdisciplinary aspects. In addition to chemistry and biology, social science subjects such as geography, history, economic, and politics can be linked. Chemical experiments may not play an important role in these latter subjects; however, the chemical and biological context of phosphates and their global environmental relevance has the potential to enrich their teaching. The reverse is also true. Teaching and learning in chemistry and science benefit from integrating the economic, geographical, and societal dimensions of a topic like phosphates to aim at a more holistic approach and a better focus at the regularly neglected societal dimension of science education (Hofstein, Eilks & Bybee, 2011).
In a transdisciplinary approach to phosphates, chemistry lessons can deal with the technical processes, the fundamentals in acid-base-chemistry, and the processes of recovery. Biology lessons can discuss plant growth conditions and the role of phosphate as a nutrient. In geography lessons, the topic can be introduced via the

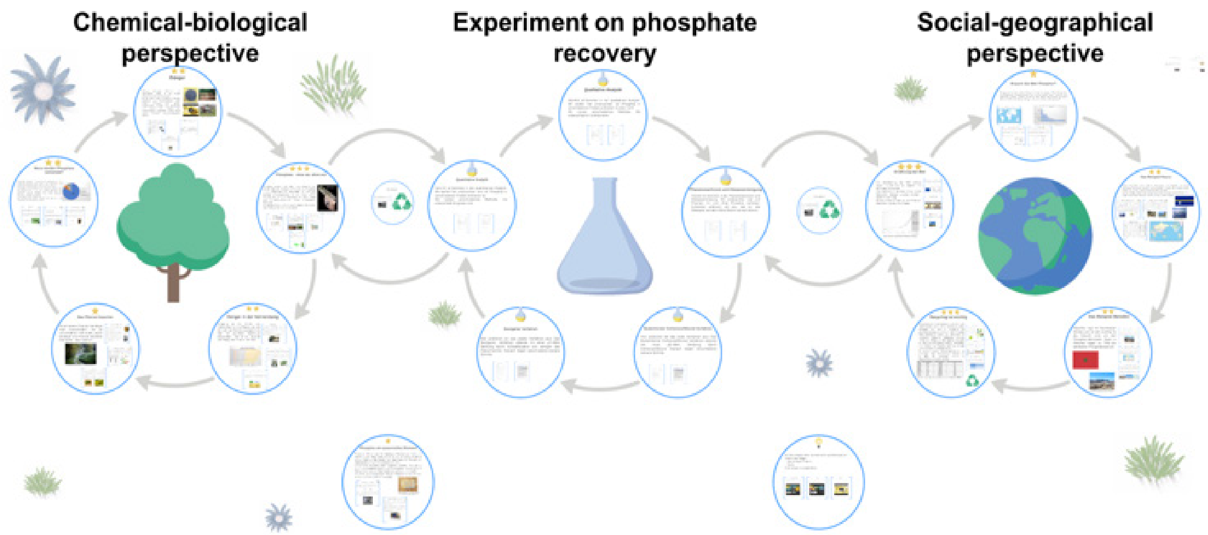

Fig. 5: Screenshot from the PREZI learning environment on phosphate recovery in German

scarcity of resources debate or the North-South divide in the use of fertilizers. The island of Nauru as an example of bad governance or the history of the unsolved Western Sahara conflict may serve as topics for politics and economy education.

For integrating the above-mentioned aspects of phosphate into the classroom, we developed a set of experiments and a web-based digital learning environment.

The experiments on phosphate recovery are described in Zowada, Siol, Gulacar and Eilks (2019 a). Here, we have adapted four of the recovery techniques, which are currently subject to environmental technology research. Other than the adapted processes, there are experiments on different analytical measures for phosphates or plant growth tests.

For teaching, the set of experiments is adapted by the instructor to fit the needs of each individual learning group. The students follow instructions for guided inquiry learning. Simple experiments on plant growth and analyzing phosphate in semi-quantitative and quantitative measures are combined with further experiments on the technical procedures for phosphate recovery. Every recovery process is based on four steps:

- Leaching – resolve the phosphate out of the sewage sludge/sewage sludge ash
- Filtration – separating the solution from solid sewage sludge
- Crystallization & filtration – crystalizing the phosphates by a precipitant
- Quantification – measuring the chemical yield using a colorimetric measure or titration

In one of these experiments, to mimic the ExtraPhos process, the pH of a phosphate solution is lowered to 4.5-5.5 by pressing carbon dioxide into the solution using a conventional soda stream. The phosphate dissolves out of the model sewage sludge. The solution is filtrated. Lime milk is added to start the precipitation. For increasing the pH above 9, sodium hydroxide is added. Calcium phosphate precipitates and is separated by filtration. The recovery rate is measured by a colorimetric test.

In our application, the laboratory work was integrated with the pre- and post-laboratory activities via a web-based digital learning environment. The digital learning environment was designed with the software Prezi. Prezi is a presentation software that allows the multi-dimensional and multi-layered arrangement of information for learning under inclusion of multimedia elements (Krause & Eilks, 2014).

With Prezi, learning trajectories are suggested for students to follow. However, the software allows the learner also to start from any section, move freely between the different elements of information, and find an individual path for learning. Assignments on Prezi environment can be individualized, so that the greatest possiblebenefits can be gained by the learners. The learning environments require an internet connection and can be reached with a browser on a laptop or computer. For the use with tablets, the free Prezi app is recommended.

The learning environment in German can be seen in Fig. 5. The learning environment was developed to prepare students for their visit to the lab where they perform experiments on phosphate recovery. The environment consists of three large areas that focus on different perspectives:

- The focus on the left is the chemical-biological aspects of phosphates, their properties, natural sources, and uses, mainly in fertilizers.
- The focus in the center is on phosphate recovery and the experiments that can be performed in schools or

non-formal and informal learning context.
- The focus on the right is on geographical, economic, and societal aspects, such as the distribution of natural phosphate reserves in the world, information on Morocco, and the story of Nauru.

Another version of the learning environment is available in English (Figure 6). The learning environment was modified to introduce the topic to general chemistry students in the USA (Gulacar, Zowada & Eilks, 2018). For this application, the focus was changed slightly, but the basic content is the same without the suggestions for practical laboratory work. This environment is structured around four questions: What is phosphate? How can we recycle phosphate? How is phosphate used? and Why is phosphate a limited resource? This environment and the prior one could be translated to other languages to engage students in similar discussions in non-English or non-German-speaking countries.

In the US version, the learning environment has been linked to a role play. After distributing roles (a farmer, an environmental activist, an industry representative, and an economist), students are charged with review of the learning environment, so they can prepare for discussion. The goal is to help students gain different perspectives and construct their own ideas through guided debate that encourages different aspects of the topic and the relationship between chemistry and today's issues and its potential to resolve them.

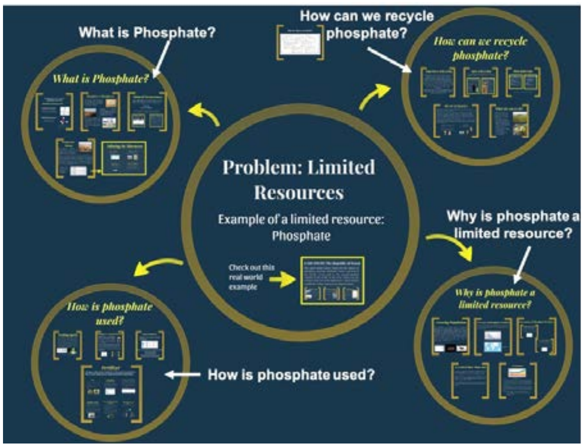

Fig. 6: Screenshot from the PREZI learning environment on phosphate recovery in English

The learning environments offers several possibilities that will increase learners' interest in and knowledge about the topic. Learners have continuous access to the learning environments, so they can get an overview of the issue, check the quick facts, or dive deeper to learn every detail wherever they want. It is recommended that, instructors guide students so they can connect the discussion of phosphorous/phosphates to broader scientific topics such as the SDGs, planetary boundaries, raw materials supply, and recycling.

Experiences

The German version of the learning environment was developed to increase students' interest in the topic, prepare them for their visit to a non-formal laboratory on phosphate recovery, as well as to accommodate post-lab activities and interdisciplinary teaching. The US version of the learning environment was used to enrich a general chemistry course with applied knowledge on how chemistry is used in current environmental technology research. In this instance, no experiments were introduced due to the rigid lab curriculum followed at the university where the intervention took place.

The learning environments and the experiments were developed in several cycles between the researchers and experienced teachers for the German version. For the English version, the researchers from both countries exchanged their expertise. In both cases, questionnaires were used in order to gain feedback using Likert-scale items and open-ended questions that were utilized for improving the digital learning environments. In Germany, surveys also included questions about the experimental instructions.

In general, the digital learning environment and the experiments were perceived positively by the German students. Students liked the design of the learning environment and the experiments, and did not face any issues while working with the digital platform or performing the experiments. Furthermore, they shared their positive feedback on coherence between the learning environment and the experiments (see Zowada, Siol, Gulacar & Eilks, 2019b).

The American students also gave positive feedback about the topic itself, which many students were not aware of: "I was shocked how much demand there was for it, and yet, we have not found an adequate way to recycle it for better use." or "While reading about the recycling process it dawned on me how little I know about this topic and how scarce the resource is...". One question asked students to rank from 1 to 10 whether this topic enriched the curriculum with 1 being weak enrichment and 10 being strong enrichment. The mean value was 6.5. When the students' preference was checked for the inclusion of such topics in the curriculum in the future although it is not connected to the test, the mean value increased to 7.3 and some commented that "Learning about phosphates and their recycling is important, although it may not deal with topics which are important for the test." (Gulacar, Zowada & Eilks, 2018). Although these students' responses were surprisingly positive for this question, it is a known fact that students are not motivated to learn the topics if they do not show up on the test. An article that highlights the details regarding the changes in students' motivation and self-efficacy after the intervention is in preparation.

Conclusion

In this paper, opportunities associated with the phosphorus/phosphates recovery topic for science education and transdisciplinary teaching were discussed. This topic can be used to meet several current demands for merging more sustainability-related topics with science education and to integrate concepts such as SDGs, planetary boundaries or critical raw materials, and the need of their recycling into teaching.
Mahaffy (2014) in North America and Müller and Niebert (2017) in Europe also explore the concept of planetary boundaries and the Anthropocene in order to identify potential topics to find connections between science curricula and current issues important for sustainability as well as advancing science teaching. Müller and Niebert (2017) suggest these topics can be easily incorporated into teaching to promote argument-based inquiry without big changes. The discussion on phosphate recovery in association with SDGs also has great potential to increasing students' engagement, and is easy to integrate into chemistry curriculum and connect to many topics including acids and bases.
The topic of phosphorus/phosphate recovery provides chances for learning basic chemistry principles. The success of this topic depends on revealing the close connection between this topic as a socio-scientific issue and the sustainability debate. Making this connection has already been suggested as an effective method for promoting the relevance of science education (Hofstein & Eilks, 2014). The approach described in this paper goes beyond such connection and includes other important and current political concepts of sustainability, such as SDGs, especially to SDG 2 "Zero Hunger", planetary boundaries, and critical raw materials. If this is done successfully, this method will get more attention by science educators and others who want to reform their teaching practices. Here, some details of using this method at high school and university levels, the materials developed to facilitate the adaption, and related observations were shared to inspire educators to start their transformative education journey.

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Resources

The German learning environments can be found at www.digitale-medien.schule/lernumgebungen.html. The English leraning environment and lab guides for experiments on phosphate recovery German and English language are available at www.idn.uni-bremen.de/chemiedidaktik/materialien.php.

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Sustainability: Equipping our Students as Future Citizens, Teachers, and Scientists

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Abstract

Ocean acidification. Global climate change. Microplastics in the environment. Chemistry instructors can and should build stronger connections in the curriculum to sustainability-related issues such as these. They are of global importance, relatively recent, interdisciplinary, and rich in opportunities to learn chemical concepts. This paper highlights one such chemical concept, the carbon cycle. Three messages are helpful as students learn about this cycle: (1) Carbon-containing compounds occur in many places on Earth; (2) These compounds move from place to place by activities of humans and the processes of nature; and, as a result, (3) where the carbon is ending up has environmental, social, and economic impacts. These impacts offer opportunities for engaging our students in learning chemistry both inside *and* outside of the classroom. Building stronger connections to our sustainability in the science curriculum holds the promise of a triple win for our students: as citizens, as future teachers, and as future scientists.

Keywords: carbon cycle, teaching and learning chemistry, sustainability

Introduction

Ocean acidification. Global climate change. Microplastics in the environment. These terms represent complex issues, each one connected both to chemistry and to other disciplines. In addition, each one connects to sustainability; in essence, our common future. Most importantly, these terms connect to knowledge that our students will find useful as future citizens, teachers, and/or scientists.

Ocean acidification is the current and ongoing decrease in the pH of seawater a result of the dissolution of anthropogenic carbon dioxide. Seawater is becoming more acidic; in turn, the concentration of the carbonate ion is being reduced. As a result, marine organisms such as corals and crustaceans may not have the concentration of carbonate ion that they need to build their shells. "In essence, ocean acidification is robbing these organisms of their necessary building blocks. … Many of these organisms form the very basis of the marine food chain, and their disappearance could potentially lead to a domino-like effect that will impact everyone" (Ocean Acidification, 2017).

Global climate change encompasses the effects of increased levels of carbon dioxide and other greenhouse gases in our atmosphere. Greenhouse gases, emitted by human activities in increasing amounts, originate from sources such as the combustion of fossil fuels and agriculture. The latest report from the Intergovernmental Panel on Climate Change highlights the concern: "Impacts on natural and human systems from global warming have already been observed (high confidence)" (IPCC, 2018).

Microplastics in the environment, together with plastics of all sizes, are a direct result of the past and current ways in which humans are producing, using, and discarding plastic. Plastic is an incredibly useful material because of its low density, strength, and durability. Unfortunately, the very properties that made plastic so useful are causing it to persist in the environment. "The Great Pacific Garbage Patch" is one of the current icons of plastic waste. Current researchers report that "Microplastics make up 94 percent of an estimated 1.8 trillion pieces of plastic in the patch" (Parker, L. 2018). Rather than consumer trash, abandoned fishing gear unexpectedly constitutes much of the mass.

What do ocean acidification, global climate change and microplastics have in common? This question has multiple answers, and five of them will be the organizing principles of this paper. In common, ocean acidification, global climate change and microplastics (1) have global implications and are recognized by people widely across the world; (2) represent relatively recent phenomena; that is, they have come to the attention of the public and/or to the scientific research community in in the last 50-100 years; (3) are interdisciplinary in nature and addressing them will require knowledge from many different fields;

(4) connect easily and well to the chemistry of carbon; in particular, to the carbon cycle; and finally, and perhaps most importantly, (5) represent challenging issues that we need to tackle to insure a sustainable future. As suggested by the title of this paper, a knowledge of chemistry equips our students as future citizens, future teachers, and future scientists.

Results and Discussion

This section highlights five of the characteristics held in common by ocean acidification, global climate change and microplastics. In addition, it discusses the implication of these commonalities for chemistry teachers and their students.

(1) Recognized for global implications

Ocean acidification. Global climate change. Microplastics in the environment. These terms exist in many languages, as shown for ocean acidification in Figure 1. Across the globe, newspaper and journal articles regularly feature reports on each one. Furthermore, each is a subject of intensive, ongoing scientific research.

These topics (and the societal issues that accompany them) have current and future global implications for everybody on the planet. It would seem logical, then, that ocean acidification, global climate change, and microplastics in the environment would find a home in college and university curricula. However, bringing issues such as these into our courses has neither been as easy or as straightforward as one might hope. Sections (2) and (3) provide insights as to why this is the case.

Fig. 1: Translations into Hebrew, Arabic, Spanish, French, and German.

(2) Relatively Recent

Ocean acidification. Global climate change. Microplastics in the environment. Although the historical timeframes are somewhat different for each issue, they all have come into public view in the past 50 years.

Consider, for example, plastics. Although celluloid first was synthesized in 1869 as a substitute for ivory, widespread use of plastics did not occur until many decades later. In the 1940s, World War II was a turning point with the successful use of polyethylene by the Allied Forces. As pointed out by the Science History Institute (n.d.), disposable plastic items such as ballpoint pens and plastic grocery bags emerged in 1952 and 1965, respectively. By the 1960s, plastic waste was visible on land and sea. By the 2000s, microplastics were observed from primary sources such as microbeads intentionally added to consumer products and from secondary sources such as larger plastic items from which smaller pieces broke off.

As another example, consider ocean acidification. As Brewer (2013) noted in his history of ocean acidification, the 1990s "saw the remarkable transition from the view of ocean CO_2 uptake as an unmitigated blessing, to emerging concern as the full scale of the impacts began to be apparent. It was in retrospect a turbulent time, as the sometimes fierce debate proceeded and critical thresholds were crossed." As pointed out by the Wood's Hole Oceanographic Institute, "Ocean acidification is a new field of research in which most studies have been published in the past 10 years. Hence, there are some certainties, but many questions remain" (2014).

The "newness" of these issues poses challenges. One set of challenges belongs to researchers, both because of the need to ask new questions and because of the need to answer the questions that remain. Challenges exist for teachers as well. Consider, for example, the knowledge base of college and university faculty members. For those in the more senior ranks, issues like ocean acidification, climate change, and microplastics emerged well after they completed their studies. Furthermore, as in any area of active research, the methods and data continue to change. Thus, teachers not only may need to learn new information in order to bring these issues to their students, but also they must continually update information for lectures and classroom activities. In contrast, topics such as stoichiometry, pH, and equilibrium are likely to be familiar and change much more slowly (if at all), thus requiring no additional preparation.

(3) Interdisciplinary

Ocean acidification. Global climate change. Microplastics in the environment. Although the connections to other disciplines may differ, in common these issues all rely on the work of researchers in multiple fields.

As an example, consider climate change. Clearly, the chemical sciences play a central role in this field of inquiry. For example, chemical spectroscopists can offer information about the molecular structures of greenhouse gases and their IR absorptions. Fuel and atmospheric chemists can provide data on the combustion and air pollution connected to fossil fuels. However, the work of researchers in other fields also advances the field of climate change. Researchers in geoscience, earth science, and atmospheric science contribute as well. In addition, social scientists offer methods, perspectives and data to help better interpret individual and community responses to climate change. See, for example, the recent U.S. report on a social sciences workshop on climate change (U.S. Global Change Research Program, 2017).

As another example, consider ocean acidification. Here, those in multiple fields contribute. As a multi-disciplinary research area, ocean acidification "encompasses topics such as chemistry, paleontology, biology, ecology, biogeochemistry, modeling, and social sciences" (Wood's Hole Institute, n.d.).

As interdisciplinary topics, can they find a home in the undergraduate chemistry curriculum? Yes, if we reinvent the field of chemistry.

G. M. Whitesides (2015) points out "chemistry must expand its mission from 'molecules' to 'everything that involves molecules.'" Yes, if we rethink the chemistry's mission. S.A. Matlin et al. (2016) point out that the "practice and overarching mission of chemistry need a major overhaul in order to be fit for purpose in the 21st century and beyond." And yes, if we can see the connections between chemistry and the real world, just as we do for chemistry in the sub-microscopic world. C. H. Middlecamp (2015) points out "By making connections, we and our students can learn to better 'see' chemistry at work in many places in our local, regional, and global communities."

The next section offers a rationale for including these issues in chemistry courses, especially the introductory ones.

(4) Connect to Carbon and the Carbon Cycle

Ocean acidification. Global climate change. Microplastics in the environment. To understand each of these issues, one must understand carbon in many different chemical forms. For ocean acidification, carbonates, bicarbonates, and carbon dioxide are key players. For global climate change, it is carbon in the form of fossil fuels, carbon dioxide, and methane. For plastics, it is carbon in the form of many different human-made polymers, including LDPE, HDPE, PET, PV, and PS.

Like other elements, carbon occurs in many places ("reservoirs") in the Earth System, including the biosphere, the atmosphere, the geosphere, and the oceans. The complex set of pathways along which carbon travels from one reservoir to another is the carbon cycle.

Many graphic artists have produced representations of the carbon cycle. A search on the internet quickly will reveal dozens of representations, all with a complex set of arrows that indicate pathways between reservoirs. In addition, some representations show estimates of the reservoir sizes, usually in gigatonnes of carbon. Figure 2 shows a simplified representation of the carbon cycle produced by the author.

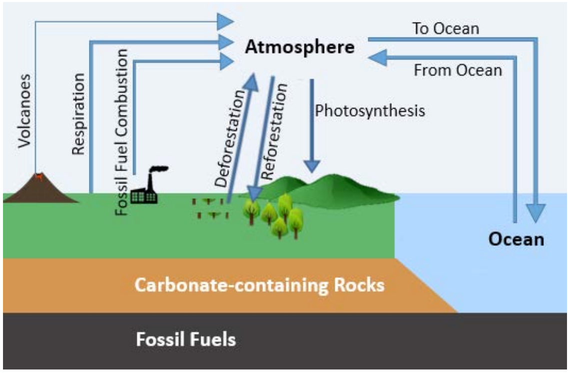

Fig. 2: A simplified representation of the carbon cycle.

Another way to simplify the carbon cycle is through strategic messages. Figure 3 shows one possibility again produced by the author for use with her students.

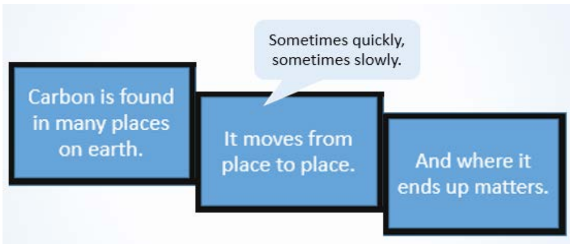

Fig. 3: Three messages for the carbon cycle.

These three messages are helpful to engage students in learning that:

(1) Carbon-containing compounds occur in many places on Earth. The air, the oceans, and vegetation are but a few of these places ("reservoirs"). Carbon-containing compounds can be difficult to recognize because they vary so much in their characteristics. For example, some are colorless gases (e.g., CO_2, CH_4), whereas others are solids (e.g., wood and plastics).

(2) These compounds move from place to place by activities of humans and the processes of nature. For example, human processes of eating and burning of a field to clear it both move carbon from one reservoir

to another. Wild fires and the dissolving of carbon dioxide from the air into the ocean are examples of natural processes that do the same.

(3) The places to which carbon is moving have environmental, social, and economic impacts. This third message forms the basis of the final item in this section.

Clearly, the carbon cycle is rich in chemistry facts, principles, and opportunities to do calculations. Table 1 lists examples of learning outcomes that connect to the carbon cycle, and Table 2 lists four examples of classroom or take-home activities. Learning about ocean acidification, global climate change, and microplastics in the environment provides a "need to know" the chemical principles. In essence, teachers can use the carbon cycle to invite students to put their knowledge to work on a topic of immediate interest.

Table 1. Sample learning outcomes for the carbon cycle

Students will be able to:

1. Name 5 carbon reservoirs on Earth. Rank them in order of size and tell in which form(s) carbon is present.
2. Name 3 processes by which carbon moves between reservoirs and write chemical equations, as appropriate.
3. Create your own representation of the carbon cycle, providing a rationale for each reservoir and pathway.
4. Use the carbon cycle to:

- explain the chemistry of ocean acidification.
- explain the chemistry of global climate change.
- propose one change that you could make in your life to help insure a sustainable future.

Table 2. Examples of activities based on the carbon cycle.

1. CO_2 has an atmospheric concentration of ~400 ppm.

a. Calculate how many gigatonnes of carbon dioxide are in the atmosphere. State any assumptions.

b. Calculate the gigatonnes of carbon in the atmosphere.

2. CO_2 has an atmospheric concentration of ~400 ppm.

a. Do research to learn how many ppm the concentration of CO_2 is rising each year and express this value in gigatonnes CO_2.

b. Propose ways to "draw down" the concentration of CO_2 in the atmosphere. The book Drawdown by Paul Hawken (2017) might prove useful.

3. Estimate the amount of carbon dioxide released:

a. burning a liter of gasoline to fuel an automobile.

b. fueling the automobiles in your city for a day.

State the assumptions you make in both parts.

4. Estimate the mass of the carbon in the form of plastic that is in the environment.

a. State your assumptions.

c. Should plastic be part of the global carbon cycle? Make an argument either way.

b. In what ways is your campus striving to reduce the amount of plastic in the environment? Suggest at least one new practice that your campus leaders could implement

Activities #2b and #4c in Table 2 point to a second avenue to engage students in learning chemistry: to look beyond the classroom. Students learn not only in our courses but also in every minute they are outside of it on the college campus.

What do students learn as they study, work, eat and play on a college campus? Many possibilities exist that connect to the carbon cycle. For example, did workers improve the efficiency of cooling and heating campus buildings? Have campus leaders implemented energy conservation measures for water and electricity? Are there alternatives to single-use plastics that end up in the environment? Whenever campus leaders take environmentally sustainable actions, teachers can use these actions to show how their campus truly is a "living laboratory for sustainability." Lindstrom and Middlecamp (2017) report how a large university in the United States has made connections from the campus to the chemistry curriculum.

(5) Connect to a Sustainable Future

Ocean acidification. Global climate change. Microplastics in the environment. All of these connect to the 2030 Agenda for Sustainable Development (United Nations Knowledge Platform, n.d.), in essence, "a shared blueprint for peace and prosperity for people and the planet, now and into the future". This agenda aims at nothing short of transforming our world in ways that better the lives of all people.

Now widely disseminated in many languages, the 17 Sustainable Development Goals (SDGs) are part of the 2030 Agenda for Sustainable Development. Most closely related to the issues presented in this paper are Goals #13 and #14, as represented in Figure 4.

Fig. 4: Two of the U.N. Sustainable Development Goals

(Sustainable Development Goals, n.d.)

To meet Goal #13, people worldwide need to take action to combat climate change and its impacts. Here are three relevant subsections of this goal, the third of which specifically calls out the responsibility of teachers. All three are quoted directly from the resolution passed in the United Nations (21 October, 2015).

13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
13.2 Integrate climate change measures into national policies, strategies and planning

13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning

To Goal #14, people worldwide need to conserve and use the oceans, seas and marine resources sustainably. Here are two relevant subsections of this goal. Both are quoted directly from the resolution passed in the United Nations (21 October, 2015).

14.1 By 2025, prevent and significantly reduce marine pollution of all kinds, in particular from land-based activities, including marine debris and nutrient pollution

14.3 Minimize and address the impacts of ocean acidification, including through enhanced scientific cooperation at all levels

Goals #13 and #14 speak to both what we can do in the present and to what we need for a sustainable future. Clearly, chemistry instructors at all levels have avenues through which to contribute.

CONCLUSIONS

Chemists have several important roles to play to insure that our common future is sustainable. One of these roles belongs to chemistry faculty members at the college level, and this paper has been prepared with them in mind. These faculty members engage our future citizens, our future teachers, and our future scientists in learning chemistry.

It is a time-intensive process to bring these issues such as ocean acidification, global climate change, and plastics in the environment into the college curriculum. The topics are interdisciplinary, constantly evolving, and most likely new to those who teach at the college level. Consequently, colleges and universities need to invest time and money in faculty development as they reimagine and rethink the undergraduate chemistry curriculum.

Why invest? This paper argues that the issues of ocean acidification, global climate change, and plastics in the environment offer rich opportunities to chemists to engage their students in learning <u>both</u> chemical principles <u>and</u> about real-world issues.

Furthermore, this paper argues that students learn <u>both</u> in their chemistry courses <u>and</u> on their college campus outside of the classrooms and laboratories. Accordingly, campus leaders also need to take actions to make the places in which their students learn, study, work, eat, and gather with friends visibly more sustainable and dedicated to stewardship of resources.

The contributions of all people at all levels are necessary to insure a sustainable future. As chemists, we have a responsibility – and a great opportunity – to be among these people.

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Contribution of Out-of-School Laboratories to the Enhancement of Scientific literacy

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Abstract
In the last decades, societal changes led to a new understanding of scientific literacy and consequently new demands for science teaching. It is shown how learning out of school meets demands that solely formal science education in school hardly fully meets. Despite the many benefits occurring from formal as well as informal learning, both forms of learning are often detached from each other. In Germany, out-of-school science laboratories became a major source of learning outside school. It is emphasized that informal learning experiences at those laboratories have the potential to a) enrich formal learning at school and thus meet demands for an enhancement of students' scientific literacy and b) provide a working example how to link science in and out of school.

Keywords: Informal Science Learning, Out-of-school Laboratories, Scientific Literacy

Introduction

Since the last more than three decades, education more and more obviously had to face a multitude of challenges (e.g. Linn, 1987). Published school-related research gave a reason for social concerns that are still relevant today, particularly in the field of science (Millar & Osborne, 1998; Osborne & Dillon, 2008). As a result, more emphasis was put on the achievement of students' scientific literacy. A concept that comprises not only content knowledge but also an understanding of how science works and how it contributes to society and personal life (National Research Council, 1996). In a complex and developed society, scientific literacy shall empower people to make decisions on scientific issues such as health, mass consumption or their environmental footprint. It gives furthermore a chance to participate in private or social debates dealing with issues. In addition, economical aspects require an appropriate level of scientific literacy in order to provide skilled labour on one hand and to ensure economic competitiveness on the other (Snow & Dibner, 2016). To promote students' scientific literacy, education cannot exclusively rely on science learning in school. More particularly, science learning also has to take into account learning that takes place outside school. Whether discussing with friends or relatives, visiting an exhibition or participating in an after-school program, informal learning occurs in a variety of places and situations. Even though historically the focus has been on formal learning, it is generally agreed in the meantime that informal learning contributes in multiple ways to science education (Fenichel & Schweingruber, 2010). Consequently, research calls for a better connection between the two learning forms (Hofstein & Rosenfeld, 1996; Stocklmayer, Rennie, & Gilbert, 2010). The article presents an example from Germany. There, the so called out-of-school laboratories became a major source for K-12 out-of-school learning. Those sites are a working example of the multiple educational benefits occurring from learning outside school (e.g. Euler, 2010). In addition, they demonstrate how to link science in and out of school.

Establishing Scientific literacy

Even though the concept of scientific literacy exists already for more than four decades (Holbrook & Rannikmae, 2009), concerns regarding goals of science education and evolving claims for reforms in the school system found expression e.g. in the National Science Education Standards (National Research Council, 1996) and its call for a new understanding of scientific literacy. In doing so, the NRC considers as science educations' foremost objective to achieve scientific literacy for all students and defines briefly: "scientific literacy is the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity" (National Research Council, 1996, p. 22). In light of many different definitions and characterizations of scientific literacy Snow and Dibner (2016) reviewed 74 related articles in order to identify commonalities. They propose three corresponding categories defining scientific literacy: (1) states of knowing to be obtained - the nature and form of knowledge required; (2) capacities to be developed - the form of actions and competencies a scientifically literate individual should be capable of undertaking and (3) personal traits to be acquired, such as a positive attitude toward science and technology. It, therefore, appears that scientific literacy is more than a pure acquisition of knowledge since it shall be related to "an appreciation of the nature of science, personal learning attributes including attitudes and also to the development of social values" (Holbrook & Rannikmae, 2009, p. 276) giving it its distinctive characteristic.

Another trait of scientific literacy is its strong link to the understanding, conduction and appreciation of scientific inquiry. This requires broad scientific abilities such as to pose questions, to conduct experiments and train experimental skills, to find explanations as well as to practise critical and logical thinking (National Research Council, 1996). Consequently, the enhancement of students' scientific literacy contributes to educational objectives in multiple ways (National Research Council, 1996; Snow & Dibner, 2016). On a personal level, it enables to participate in discussions, to make decisions and to take informed actions. A scientific literate citizen is furthermore more employable and skilled for future work tasks. This also refers to scientific literacies societal objectives, which shall moreover ensure an economy's competitiveness but also to make a society able to cope with social problems and large-scale challenges. In conclusion, Hofstein, Eilks and Bybee (2011) stress out, "nearly all concepts explicitly emphasized the societal dimension as being an essential part of developed scientific literacy" (p. 1462).

Learning out of school

Science learning not only takes place in school. Learning also happens in a variety of venues and occasions outside of school. In order to get an impression on its diversity, the National Research Council (2009) subdivided out-of-school science learning in three forms: (1) everyday experiences, such as conversations with family or friends, or watching a documentary; (2) designed places, which is related to sites like science centres, zoos or museums; and (3) programs, like the attendance in a field trip, a science club or an after-school activity. Such learning occasions are referring to the term informal science learning. In contrast to that, formal science learning defines learning taking place in a school context. More in particular, Rennie (2007) characterizes informal learning as occasions where: (a) both attendance and involvement are voluntary or free-choice, rather than compulsory or coercive; (b) the curriculum has an underlying structure that is open, offers choices to learners, and tends not to be didactic; (c) the activities are nonevaluative and noncompetitive, rather than assessed and graded; and (d) the social interaction is among groups heterogeneous with regard to age, rather than constrained between same-age peers and formalized with the teacher as the main adult (Rennie, 2007, p. 127).

In light of out-of-school learning's diversity, some researchers propose to further distinguish between informal and non-formal learning. The latter in this way holds characteristics of informal and formal science learning (Eshach, 2007; Malcolm, Hodkinson, Colley, Hodkinson, & Colley, 2004). It is considered to be more prearranged and structured, also learning is more led by the teacher or guide (Eshach, 2007).

In light of the many educational objectives along with challenges in science education, research stresses the importance of out-of-school science learning (Fenichel & Schweingruber, 2010; Lin & Schunn, 2016; National Research Council, 1996). More in particular, "informal experiences are recognised as complementing and extending learning opportunities for young people beyond those available in school" (Dewitt, Archer, & Archer, 2017, p. 356). Reports of the National Research Council as well as the National Science Foundation point out informal environments' possible learning outcomes. While learning science in an informal way, students need to generate, to understand and to use different concepts as well as need to learn through the use of explanations, models and facts. This deepens students' knowledge through practising skills of inquiry. What is more, informal learning also affects attitudes toward science. This might turn out through an increasing interest in science or a higher motivation. Students may also question their relation towards science or specific topics.

A need to link learning inside and outside school

There has been a controversial discourse about the contribution and value of both learnings inside and outside school (Stocklmayer et al., 2010). Nevertheless, the two forms of learning achieve complementary as well as overlapping goals (National Research Council, 2009). Successful science education, therefore, requires formal as well as informal learning. Accordingly, researchers for more than two decades demand a better collaboration in order to "bridge the gap between formal and informal science learning" (Hofstein & Rosenfeld, 1996; Stocklmayer et al., 2010). It is assumed, that due to a better link between the two forms of science learning, students' learning opportunities become more diverse and more numerous. It is therefore likely to cause a higher motivation, more concepts of learning and knowledge but also new skills and abilities (Fallik, Rosenfeld, & Eylon, 2013). An appropriate linkage also affects students' affective states. Accordingly, applying content knowledge with authentic problems gives students the chance to perceive scientific issues more relevant and meaningful (European Commission, 2015). Bridging the gap between informal and formal learning also gives the opportunity to prevent institutional limitations at school. Schwarz and Stolow (2006) for that matter argue that formal science suffers from four constraints: (1) time-related limitations – since school has a fixed time frame; (2) limits of structure – referring to a fixed physical setting such as classrooms; (3) limits of inertia and bureaucracy – in relation to inflexible administrative structures; as well as (4) limits of priorities – criticising a partially narrow focus on specific learning outcomes unable to meet more extensive demands such as the establishment of scientific literacy. However, claims are also directed towards informal sites. An enhanced collaboration between formal and informal sites require better adoptions of informal learning activities to the curriculum at school and has to consider restrictions and demands of schools. Accordingly, it is supposed to not only provide qualified and suitable staff at the informal learning places but also afford professional development to teachers (Stocklmayer et al., 2010). Stocklmayer, Rennie and Gilbert (2010) who intensively argued about the role of formal and informal science in light of an effective science education propose three models or rather scenarios for their relationship. The first one refers to formal and informal science learning separated from each other, which means that each type of learning fulfils its educational objectives independently. The second model assumes that formal and informal science learning have a common overlap. In this regard, formal science learning remains the major source of science learning but also uses possibilities to conduct informal science learning. The third scenario expresses the idea of a full integration of informal science learning in the context of formal learning sites.

Providing informal science learning through out-of-school learning laboratories

Educational challenges as mentioned above also happened in Germany. More particularly, there was increasing dissatisfaction with outcomes of formal science learning, culminating in, what was called "PISA shock". Referring to appallingly poor results in international student assessment PISA in 2000 (Stanat, Artelt, Baumert, & Klieme, 2002). As a result, high expectations towards informal science learning led to a boom of so-called out-of-school laboratories. As of today, a number of 378 places exist in Germany (LernortLabor e.V., 2018). As the name already suggests, the places offer regular out-of-school activities in scientific laboratories. In doing so they are dedicated to school students and operated by various institutions but foremost universities, research centres and industry (Euler, 2004; Haupt, 2015).

The places' affiliation to non-school organizations gives the chance to establish an authentic environment where students are involved in scientific inquiry and conduct practical work (Euler, 2010). The content which is provided is related to students' everyday experiences with science but also want to connect school and scientific knowledge (Euler, 2010). In light of the characteristics of formal and informal learning, it turns out that the out-of-school laboratories show aspects of both learning forms. More in particular, the term non-formal learning applies best for learning that takes place in the laboratories. A number of studies already showed that practical work in laboratories hold many beneficial educational outcomes (Hofstein & Lunetta, 2004; Lunetta, Hofstein, & Clough, 2007). Regarding the out-of-school laboratories, joint and major objective is to promote students' interest in academic STEM disciplines (Di Fuccia, Witteck, Markic, & Eilks, 2012; Euler, 2010). In addition, the laboratories, on the one hand, aim to improve the perception of science and its perceived relevance. On the other hand, the places want to contribute to a higher scientific knowledge and a better understanding of the nature of science (Euler, 2010; Plasa, 2013). Taking the characteristics and objectives of the out-of-school laboratories into account, it can be concluded that the places have a high potential to efficiently promote students' scientific literacy.

Research on out-of-school laboratories

In the last 15 years, the number of empirical studies on out-of-school laboratories was constantly growing. Taking into account the out-of-school science laboratories' main goal, research particularly focusses on the enhancement of students' interest. The findings yield a uniform picture and indicate the out-of-school science laboratories' ability to successfully promote students' interest in science (Engeln, 2004; Glowinski, 2007; Guderian, 2007; Pawek, 2009; Scharfenberg, 2005). This applies for all three valences of situational interest, namely its feeling-related and the intrinsic as well as value-related component. Moreover, it turned out that both genders were equally affected (Engeln, 2004; Glowinski, 2007). That is particularly pleasing for the field of science but especially for chemistry and physics. Even weeks after the lab activity, the evoked interest was still verifiable (Engeln, 2004; Pawek, 2009). Nevertheless, it seems that the caused situational interest decreased over time which especially applies to its feeling-related and the intrinsic component (Engeln, 2004; Guderian, 2007; Pawek, 2009). Also, students' motivation to learn science increased after attending the out-of-school laboratory. It could be demonstrated that this even caused intrinsic motivation for learning at school (Brandt, 2005). Furthermore, investigations also assessed students' dispositional values. It turned out that out-of-school laboratories' activities are able to raise students' self-concept slightly (Brandt, 2005; Pawek, 2009). Along with student' self-assessment expressed by their self-concept, also the perception of science, in general, changed positively (Weßnig, 2013). It is thus not surprising that laboratory activities also have the chance to affect vocational orientations (Weßnig, 2013). Studies by Engeln and Pawek tried to identify factors inside the laboratory environment that influence their outcome. In doing so they assessed a number of so-called laboratory features, such as students' perceptions of the activity's challenge, openness, comprehensibility and others. As a result, laboratory features such as challenge, authenticity, comprehensibility (Engeln, 2004) as well as relevance and atmosphere (Pawek, 2009) are supposed to have an effect on the places outcome. However, almost all of the mentioned studies on out-of-school laboratories demand a greater coherence between school and laboratory (Brandt, 2005; Engeln, 2004; Glowinski, 2007; Guderian, 2007; Pawek, 2009). This is coherent with the previously presented demands regarding demanding to bridge the gap between formal and informal science learning.

An online portal links school with out-of-school laboratories

In light of demands calling for a better link between school and programs in out-of-school laboratories, a study was conducted by Streller (2015). In doing so, a preparation and post-enhancement regarding the out-of-school laboratory was developed and provided for schools. The implementation was via an online portal, which gave each student a personal excess to e-learning courses specially developed for a specific program at the out-of-school laboratory. In doing so, the preparation course gave access to required content knowledge for the lab activity and was aligned with prior knowledge from school. Furthermore, a part with additional information motivates students to engage with the prepared topic. Therefore, the content was linked to the everyday life of the students. The follow-up course which served for the post-enhancement dealt with the knowledge gathered from the activity in the out-of-school laboratory. In doing so, the new knowledge was related to the school curriculum as well as to research and science. A comparative analysis assessed treatment group students who used the online portal and control group members who just regularly attended the laboratory without any special preparation or post enhancement. Via a longitudinal study, pre-, post-, and follow-up measurements were conducted: right before the activity at the out-of-school laboratory, right after it, and six to eight weeks later. The study's main objective was to identify the impact of the preparation and post-enhancement on the out-of-school laboratory's outcome. Therefore, students' interest, dispositional values and perceptions have been assessed. In order to gain further insight, based on students' areas of interest three classes were identified grouping students with a low, medium and high affinity for science.

The effects of an online portal that links formal and informal places

Findings of the study revealed a number of benefits occurring from the online portal. The most particular effect was detected regarding students situational interest. It turned out that right after the out-of-school activity treatment group students achieved a significantly higher situational interest. This applied for all of its three components but most prominent for its feeling-related component (feeling-related component: $t(488)=-8{,}718$, $p<0{,}001$, $r=0{,}37$, intrinsic component: $t(509)=-4{,}060$, $p<0{,}001$, $r=0{,}18$, value-related component: $t(497)=-3{,}351$, $p<0{,}01$, $r=0{,}15$).

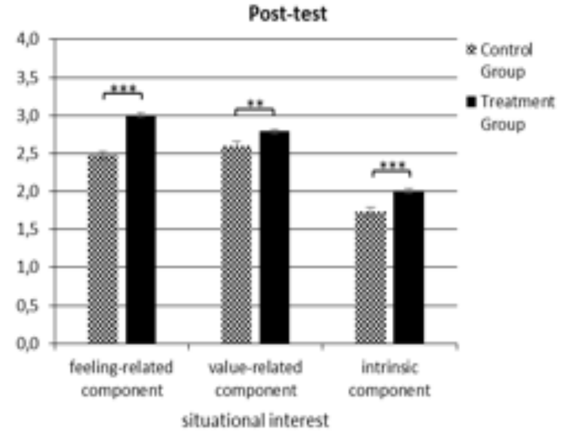

Fig. 1: Means of students` situational interest subdivided into its three components and distinguished between treatment and control group members.

The results are displayed in Figure 1. However, differences between treatment and control group participants seem to diminish over time since no significant disparity have been found for the follow-up test. In addition, students' interest in a career in physics was assessed, referring to dispositional values. It turned out that during all three stages of the assessment, control group students achieved lower levels than their treatment group counterparts. More in particular, right at the beginning of the activity in the out-of-school laboratory students that used the online portal already had a higher interest in a career in physics with a small effect size ($t(536{,}95)=-3{,}06$, $p<0{,}01$, $r=0{,}13$). After the activity this gap slightly increased and was more significant, too ($t(450{,}51)=-3{,}60$, $p<0{,}001$, $r=0{,}17$). Even though significant differences still remained for the follow-up test, the effect was of minor power and less significant ($t(369)=-2{,}03$, $p<0{,}05$, $r=0{,}10$). Effects were also detected regarding students' perception of the activity in the laboratory. For this reason, different laboratory features, namely challenge, comprehensibility, openness, support, relevance, and involvement have been investigated. The results demonstrate that treatment group students perceived the activity better. This applies foremost regarding the activity's comprehensibility (t(511,00)=-5,58, p<0,001, r=0,24) and less pronounced for its relevance (t(850)=-2,03,p<0,05, r=0,07). Taking into account students' interest profile, it was demonstrated that overall, students with low, medium and high interest in science were positively affected through applying the online portal. More particularly, students with low science interest were the only subgroup showing positive effects regarding all the components of situational interest. Another remarkable result was related to students with a high interest in science. Even though their feeling related component was effected only, this subgroup holds the highest effect sizes of all three groups. The results are displayed in Table 1. The fact that only parts of the online portal were compulsory also reflects in the participation figures. Accordingly, 97 % of all treatment group members participated in the compulsory preparation part. A share of 46% also did the additional, voluntary preparation part. After the activity, about 41% still used the online portal in order to voluntarily use the post-enhancement.

Table 1: Post-test results of the conducted t-test between treatment and control group distinguished for each class regarding their means for the three situational interest components.

Comparison	Feeling-related component	Value-related component	Intrinsic component
Group "low" CG & TG	t(257)= -5,55, p<0,001, r=0,33	t(257)= -4,18, p<0,001, r=0,25	t(198,67)= -4,14, p<0,001, r=0,28
Group "moderate" CG & TG	t(297)= -3,34, p<0,01, r=0,19	t(297)=0,17, n.s.	t(297)=-0,3, n.s.
Group "high" CG & TG	t(103,58)= -5,25, p<0,001, r=0,46	t(292)= -0,35, n.s.	t(291)= -0,87, n.s.

Conclusions

The intention of this article was to show the numerous benefits occurring from informal learning and in doing so to point out its importance for the achievement of educational goals. It turned out that in contrast to formal science learning, informal science learning can lead to broader outcomes. It, therefore, plays an essential role in the achievement of complex objectives such as the development of students' scientific literacy. Out of the many places and occasions that offer informal learning opportunities, this article discussed so-called out-of-school laboratories which had stunning development in Germany and are now one of the main sources for informal learning there. The presented research gave evidence that the proposed outcomes of informal science learning can be achieved by such places. Particularly, on the one hand, out-of-school laboratories positively affect students' affections and dispositions such as interest, motivation, vocational orientations and also their perception of science in general and certain topics in specific. On the other hand, students not only receive access to modern science that is dealing with everyday issues but also further their knowledge while performing tasks in the laboratories. Consequently, those outcomes, as well as the strong focus on scientific inquiry and practical work, make the out-of-school laboratories an important contributor for a profound and comprehensive scientific literacy.

Based on research in informal science education as well as empirical studies on out-of-school laboratories, a better coordination between the formal and informal sites was demanded. It is demonstrated that the presented online portal has the potential to successfully link both sites. In doing so it positively affects students' interest as well as to some extent even their dispositions on the one hand. On the other hand, it also makes scientific contents at the laboratory more comprehensible and relevant for students. In light of the online portal's significant impact on the out-of-school laboratory's outcome, it is therefore assumed, that the online-portal has the potential to enhance students' scientific literacy.

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Regional Networks and Regional Didactic Centres to foster Science Education

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Abstract

This case study presents the development of networks in education, using the Austrian IMST (Innovations Make Schools Top) project as illustration. The regional networks are coordinated in every Austrian federal province by groups made up of teachers, representatives of the educational authorities, and members of academia. In the framework of the IMST project, all networks are monitored by a team of the Institute of Instructional and School Development at the University of Klagenfurt. This article presents theoretical concepts, network structures and network activities, as well as research data.

The IMST project

The nation-wide 'IMST' (Innovations Make Schools Top) project aims at improving instruction in mathematics, science, IT, German language (the latter targeted at literacy) and related subjects. The focus is on student and teacher learning.(www.imst.ac.at)

Since 1998, the Institute of Instructional and School Development at the Alpen-Adria-Universität Klagenfurt has been repeatedly commissioned by the Austrian Federal Ministry of Education, Science and Culture with carrying out the project. It developed in three phases: (1) analysis of Austria's disappointing results in the Third International Mathematics and Science Study (TIMSS 1995); (2) development- and research project IMST (2000 – 2004); (3) build-up of a support system for schools (2004 – ongoing). In the first and second phases, the project was targeted only at secondary higher schools. Since then, it has been opened to the entire educational system (K–12 and teacher education). The project currently involves some 21,000 teachers who participate in projects, attend conferences, or cooperate in regional and thematic networks.

The IMST 'Regional and Thematic Networks' programme supports regional networks in all nine Austrian provinces, and three thematic networks which operate at national level. Within the IMST thematic programmes, teachers put innovative instructional projects into practice and receive support in terms of content, organisation and finance. Furthermore, 18 Regional Educational Competence Centres (RECC) in science subjects were implemented all over Austria as a cooperative structure between universities and teacher education colleges. To some extent, they fill the gap of lacking subject didactic centres in higher education throughout Austria and provide research-based didactic professional development for teachers. Gender sensitivity and mainstreaming are key project principles; their implementation is supported by the Gender Network. Evaluation and research are integrated at all levels to assess the impact of IMST.

The following three goals are pursued in the medium term by the establishment of the networks:

- Raising the attractiveness and quality of lessons and school development (creating concentrations) in mathematics (M), biology and ecology (BIU), chemistry (CH), physics (PH), information technology (INF), geography (GWK), descriptive geometry (DG) and related subjects, as well as cross-curricular initiatives in secondary academic, vocational and secondary general schools, as well as primary schools (since 2007). The results and content of the IMST project create a framework for guidance for the instructional and school initiatives in the network;
- Professional development for teachers;
- Involvement of as many schools as possible (widespread effect).
- The regional networks were formed according to the following two principles:

* Use of existing personnel, institutional and material resources in the federal provinces.

* The persons and organisations involved take responsibility for the development of regional networks in each of the federal provinces.

The idea underlying IMST allows a steering committee in each regional network to coordinate and be responsible for the creation of content. In these steering committees, the subjects of maths, science, IT, and the province education board (including since autumn 2007 teacher training colleges) are represented.

To emphasise the fact that the regional networks are sustainably embedded in the federal provinces, IMST support is linked to each of the federal provinces, and resources (teaching hours, funds) are made available.

The detailed task profile of a regional network is geared to the needs of the schools in the region and to existing resources. It always includes the establishment of a platform for schools and teachers, arranging opportunities for sharing experiences and further education, supporting the creation of concentrations and their development in schools, developing a pool of experts to advise on didactic and school matters, drafting an annual report and interim reports on the activities of the regional and thematic networks, as well as evaluation.

The networks are aided by financial support, a platform for ongoing process management, two seminars per year for the network steering committee members, public relations (folder, IMST newsletter), accompanying research and studies on the development of networks through the network team at the Institute of Instructional and School Development.

Theoretical background of the IMST networks

Present-day discourse on networks generates a variety of meanings; in virtually all debates, networks are loaded with hopes and desires for a better social, business and working world. Networks can be understood as metaphors of post-modern society. They are expected to be more effective in coping with individualisation, fragmentation and functional differentiation in society than traditional organisations and institutions. Networks are considered as new and desirable forms of cooperation, and of joint social and economic action. In trying to define the substance and character of networks, metaphorical usage covers theoretical approaches as well as practical descriptions of features and specifics. They all shed light on the shortcomings of traditional organisational structures and processes and try to grasp the uniqueness of "networks".

In the wake of general social trends and structural transformation, networks in educational contexts have become increasingly attractive in educational systems. In the 1990s, systemic school modernisation processes were launched by policymakers, prompted by the need for reformatory change in the light of the results of international assessment surveys like TIMSS (1995 and further), PISA (2000 and further), etc. Having proclaimed "school autonomy", the central administration has been more and more focusing on contextual steering activities whilst delegating responsibilities to decentralised units (Posch & Altrichter 1993, Fullan 2007). Less bureaucratic steering generates a need for alternative coordination (Altrichter, 2010). Intermediate structures (Czerwansky, Hameyer & Rolff, 2002) such as networks are expected and conceived to fill a structural gap and take over functions traditionally assigned to the hierarchy. Ideally, networks are conceived as an interface and an effective means of pooling competencies and resources (Posch, 1995; OECD, 2003). As intermediate structures, they manage autonomy and interdependent structures and processes, and try to explore new paths in learning and cooperation between individuals and institutions.

The development of the IMST networks was based on social networking theories. In this process, authors consider the following aspects paramount:

Mutual Intention and Goals: Networks orientate themselves on a framework topic and goal horizon that has been agreed upon by all (Liebermann & Wood, 2003).

Trust Orientation: Mutual trust is a prerequisite for exchanging and sharing knowledge, and therefore a prerequisite for learning. Networks encourage new, innovative paths (risk-taking) and support conflict resolution (McDonald & Klein, 2003).

Voluntary Participation: Networks do not impose sanctions. Interventions can be vetoed (Boos, Exner & Heitger, 2000).

Principle of Exchange (Win-Win Relationship): Information can be exchanged whenever an occasion arises. Mutual give and take is vital. Power and competition, while not being excluded, are addressed and dealt with between the centre and the periphery on the same level (OECD, 2003).

Steering Platform: Networks are not occasional interactions, but institutionalised configurations. Networks have to be coordinated and maintained in order to support exchange processes, cooperation and learning (Dobischat, Düsseldorf, Nuissl & Stuhldreier, 2006).

Synergy: Networks enable synergies through structural organisation; they offer an alternative to classic rationalisation strategies and are characterised by the dismantling of structures (Schäffter, 2006).

Learning: Networks are support systems based on reciprocity. Those involved can exchange views and information, and cooperate on mutual concerns. They learn from and with each other (Czerwanski et al., 2002).

Per Dalin's (1999) description of how networks function in education is an important theoretical basis underlying the formation of regional networks in IMST. Accordingly, networks have an *informative function* which becomes visible in a direct exchange of practice and knowledge for teaching and school, and as a bridge between practice and knowledge.

Through networking, further opportunities for learning and competence development (professionalisation) are encouraged by the members, who establish the *learning function*. Trust is a prerequisite for cooperation within a network. It is the basis for the *psychological function* of a network which encourages and strengthens individuals. In a fourth function of networks, *the political function*, enforceability of educational concerns increases, following the motto “together we achieve more”.

Accompanying research

On the basis of the objectives and the underlying theoretical concepts, the IMST-regional networks are evaluated and researched concomitantly to facilitate and promote development processes. The most recent accompanying research study was conducted in the school year 2014/15 and is based on the goals and frameworks of IMST and on the results of previous evaluations.

The central methods of this study were a systematic analysis of the steering group’s annual reports from 2010 to 2014 and 23 guided interviews conducted with coordinators and steering group members from the nine regional networks, as well as with kindergarten pedagogues and teachers not belonging to the steering group. The extensive data collection is based on a combination of the document analysis with the guide-based interviews and was extended with unstructured observations at individual network events, internet research and individual inquiries or briefings (Ziener 2016).

Thematically, the study was guided by eight research questions that refer to the goals and priorities of the networks and their successes, challenges and impacts. However, network concepts and network features such as structure, dynamics, information and communication as well as reflection, evaluation and learning processes were also included (Ziener 2016).

Selected results of the accompanying research

The accompanying research of the regional networks aimed at a holistic assessment of the complexity of the network activity in terms of a development and impact orientation. In the following sub-chapters, those aspects are selected, on the basis of the accompanying research, that have proven to be most constitutive for the development of the regional networks (Rauch & Korenjak 2018, Rauch 2016).

Structure, development and dynamics of the networks

Regional networks are open networks that are constituted and developed in the context of their respective objectives and activities. Due to different regional needs, there are also structural differences in the individual federal states. Generally, the provincial school council or city school board acts as the responsible institution of the regional network, partly together with the university colleges of teacher education. In Upper Austria and Carinthia the regional networks are also supported by scientific associations (INIZIA, Nawi4you).

Each regional network has a steering group and each of them form the central hub from which network relations are developed at the personal and institutional levels. The steering groups differ in their size and composition, depending on the inclusion of school types and subjects as well as the distribution of tasks and responsibilities within the steering group. Relations within the regional networks are developed through the exchange of information and experience in the context of (further education) events and in cooperation between teachers, educational institutions as well as between science and school practice, the formation of subnetworks, personal discussions and good cooperation.

The regional networks were founded between 2003 and 2008. Thereby is not a continuous, but a dynamic network development with fluctuations to observe. In the first years, until about 2008/09, a high dynamic of the regional networks due to the development of the networks and the connected networking and development processes can be observed. Thereafter, a period of consolidation began, during which the various network activities were established and further developed (Ziener 2016).

Main topics of the regional networks

The regional networks include a variety of activities such as industrial cooperation, implementation and development of Science Days, network days, days of natural sciences, multi-day training sessions, annual projects, small-scale project funding, teacher training and other services.

These activities of the regional networks can basically be subdivided into two main areas, the teacher training and the small-scale project funding which both directly affect the lessons and interact with each other. Both focal points also offer approaches to networking by promoting the exchange of information and establishing communication structures. The aim of these focuses is to increase the attractiveness and quality of teaching in science subjects and to further develop teacher professionalism (Ziener 2016).

Network perception of the involved actors

In about half of the individual interviews, network definitions were sketched in the approach and in some further interviews the networking aspect was discussed. However, this networking aspect was not always clear. In about two-thirds of the interviews, statements revealed that the regional network is equated with the steering group, which is often associated with a certain supply orientation. This highlights the importance of the steering group as an intermediary platform (Dobischat et al. 2006).

The question of the significance of the regional network allows two interpretations: the general significance of

the network from the point of view of the interviewees as well as the personal significance. On a general level, the networks offer, for example, the opportunity to get in contact with science teachers across all types of schools. On a personal level, for example, the possibility of working together with colleagues from other school levels or subjects is seen.
In summary, networks are seen as a grouping of people with similar interests and goals to promote science education in various types of schools and school subjects. In addition, the networks are characterized as a communication structure, platform and information hub for the exchange of teaching ideas, information and best-practice examples. Important factors for the network development named, were the commitment, vision and motivation of the members of the steering group. This refers to a certain supply structure of the regional networks (Ziener 2016).

Achievements and effects
The success of the regional networks is closely linked to the objectives and priorities of each regional network. A quarter of the interviewees' named successes of the individual regional networks refer to specific training, events or projects offered in the respective network. Some see the successes in the impact on the school, the classroom and the teachers. Further successes are related to specific activities of the individual regional networks or the specific conditions in the federal state. The assessment of the impact of networks on MINDT-teaching and on the professionalization of teachers is based on the own teaching practice of the steering group members, or on feedback from further education participants, project presentations, evaluation data or face-to-face interviews. It is important to note that the impact on teachers, students and the lessons is multicausal, in which the work of the regional networks is only one aspect.
Problems and challenges are to be seen as the success of the regional networks depending on country-specific priorities and objectives. Challenges addressed are the resource problems on a financial, personal and temporal level. The latter is caused by the current restructuring of the school system, which consumes a large part of the resources. As a general challenge, the increasing competition among other commercial, suppliers in the NAWI area is seen, whereby cooperation and networking are becoming increasingly important (Ziener 2016).

Innovations and learnng processes
Innovations are not necessarily understood by IMST as something absolute new, but is rather referred to Austria as a whole or the respective state and the time when it was created. Part of the innovations mentioned by members of the steering group relate to the success of the regional network. The regional networks themselves were an innovation in their founding due to the network-based cooperation between teachers and relevant educational institutions and their function as a communication platform across subjects, school-types and school-levels.
Among the innovations of IMST within the scope of the regional networks belong also the regional subject didactic centers. The development of those began very early in 2006 and reached its peak in 2014, when the quality label "Regional Educational Competence Center" was awarded for the first time by the Austrian Ministry of Education.
In 2007, district networks were initiated as a local networking opportunity within the federal states and German was included in the IMST-project. The Experimentale in Upper Austria and the SEMI High Tech University in Carinthia are still unique and innovative in this form in Austria. The successful format of the Science Day in Salzburg was also developed a little later under the motto "Students for Students - Learning from each other, with each other, for each other". Another early development is the promotion of teaching projects in Tyrol and Styria. Also innovative are concepts such as "learning through teaching", the cooperation between natural sciences and German as well as the cooperation with industry. The regional networks are constantly promoting innovations such as didactic innovations and the use of new technologies and media in the classroom. Partly, the regional networks have been involved in the development of teaching materials, experiment kits or the design of appropriate further education.

Most of the learning processes were described by the interviewees in connection with the steering group work. These are limited to operational measures such as the development of further education, organization of events, project management, as well as reflection and evaluation. Further learning processes are also seen in subject-related and didactic teacher training, where frequently new research results, topics currently being discussed or interdisciplinary topics are taken up. In some cases, especially workshops or projects, targeted learning processes have been initiated. Finally, reference was also made to informal learning processes resulting from exchange and networking. Cross-school and cross-curricular initiatives have also created new forms of mutual learning, such as the presentation of good-practice examples and regular collaboration in learning communities. Learning processes also develop for teachers in the implementation of teaching projects and in addition to dealing with the topic, competences in the field of project organization, documentation and presentation are also gained (Ziener 2016).

Conclusions

Social contacts are indispensable for the creation of structures and the transmission of information. Therefore, the strategy of using and developing existing regional structures was successful. Such developments, however, can only happen in small steps. Support from the province education boards is quintessential for the continued development of regional identities in networks. The duties of the steering committee and its coordinator(s) are diverse and can only be accomplished by teamwork.

The regional networks carry out creative projects and thereby try to raise the attractiveness of science lessons in cross-curricular cooperations which involve several school types and use innovative methods. Networks are seen as a complementary strategy for disseminating innovations and reform. On their own, however, networks are hardly in a position to bring about system change (McDonald & Klein, 2003). The question arises how they should develop to be able to support reform. In this context, the highly dynamic development of regional didactic centres (since 2007) is noteworthy. These centres developed within the network structure. They provide a place for didactic further education, development and research in the region. By their design, they are to act as a cooperation structure between universities (responsible for the education of teachers at secondary academic schools with a tradition in science) and teacher training colleges (responsible for the education of compulsory school teachers and for further education with a tradition in practical experience), and generate impetus for the design of education programmes. In the coming years, the focus will be on constructively creating collaboration between networks and didactic centres, as well as on quality development and assurance through process management, process guidance, evaluation and research.

Based on the study presented, the following general findings can be drawn (Rauch, 2013):

- Good practice cannot be cloned, but exchanging experience on a personal level promotes learning and innovation.
- Networks in education offer goal-oriented exchange processes among teachers *(information function)* which support the professional development of teachers (i.e. fresh ideas for classroom teaching, interdisciplinary cooperation at schools) *(learning function)*.
- Networks have the potential to create a culture of trust, with the effect of raising self-esteem and risk-taking of teachers (*psychological function)* and upgrading science at school *(political function)*.
- It is necessary to maintain a balance of *action & reflection* (goal-directed planning and evaluation) and *autonomy & networking* (analysis of one's own situation, but also support by "critical friends" i.e. colleagues at school, and the IMST-facilitator) in order to set up a sustainable support system for schools.
- Evaluation and research need to be driven by an interactive link between an interest to gain new knowledge and a developmental interest. A culture of self-critical and collective reflection might flourish, but reflection should not hamper a project from being taken forward (see previous aspect).
- There are a number of risks, e.g. that:
  - a network moves away from the interests of teachers and from the teaching and learning of students
  - common visions and goals disappear,
  - the network fails due to weak coordination and steering,
  - the network fails due to a lack of resources (money and time),
  - the network mutates into a bureaucracy.

The overall challenge might be described as keeping momentum between structures and processes or, in other words, between stability and flow to enable sustainable development of learning.

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Professional Learning Communities (PLCs) of Chemistry Teachers

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Abstract

Creating teachers' professional learning communities (PLCs) is an effective bottom-up way of bringing innovation into the science curriculum and professional development. The models of PLCs are based on principles of learning that emphasize the co-construction of knowledge by learners, who in this case are the teachers themselves. Teachers in a PLC meet regularly to explore their practices and the learning outcomes of their students, analyze their teaching and their students' learning processes, draw conclusions, and make changes in order to improve their teaching and the learning of their students. It was found that participation in a PLC influences teaching practice, so teachers become more student-centered. Moreover, the teaching culture improves as the community increases the degree of cooperation among teachers, and focuses on the processes of learning rather than the accumulation of knowledge. This enables students to be innovative, creative, and critical. In addition, trust is developed among the participants, which enables them to discuss and analyze their students' cognitive and affective problems, misconceptions, and learning outcomes.

Teachers' Professional Learning Communities (PLCs) – theoretical framework

Creating teachers' professional learning communities is an effective bottom-up way of bringing innovation into the science curriculum and professional development. The models of professional learning communities are based on principles of learning that emphasize the co-construction of knowledge by learners, who in this case are the teachers themselves. Teachers in a professional learning community meet regularly to explore their practices and the learning outcomes of their students, analyze their teaching and their students' learning processes, draw conclusions, and make changes in order to improve their teaching and the learning of their students. (Tschannen-Moran, 2014). The concept of PLC arose in the field of education in the context of workplace-based studies conducted in the 1980s that addressed teachers whose professional relations were characterized by continuous striving for improvement, focused on student learning, and who collaborated and explored their work. Such relationships differ from the norms used in the teaching of a more individualistic culture, which typically characterizes schools as a place of work (Lortie & Clement, 1975).

In 1982, Little conducted an anthropological study of six primary and secondary schools in four counties in the western US. He found that schools with norms of collaboration, collegiality, and research could respond better to the pressures of external changes and education initiatives. This finding was reinforced by Rosenholtz (1989), who combined surveys and interviews with 78 primary schools. She distinguished "rich" and "poor" schools with respect to learning. The learning-rich schools were more likely to establish norms of cooperation and continuous improvement.

Newmann (1996) argued that a professional community of teachers offers a supportive environment in which teacher learning can occur. For example, the Center for Organizing and Building in Schools at the University of Wisconsin conducted systematic research on 24 primaries, junior high, and high schools in which structural and organizational changes were carried out, with an emphasis on the quality of instruction in mathematics and social sciences. It was found that aspects of a school's professional community that include common norms and values, a focus on student learning, reflective dialogue, transformation of teachers' practice in public classes, and a focus on collaboration, are linked to robust teaching and support for teacher learning.

In a series of articles based on analysis of the NELS:88 databases, Lee, Smith and Corninger (1997) argued that more organized schools produce higher levels of teacher satisfaction, positive student behavior, problem-solving pedagogy, and understanding and learning in mathematics and science. "Our results indicate that when there is a professional community of teachers - when teachers are taking responsibility for the success of all their students - more than learning is occurring" (Lee et al., 1997, p. 142).

Shulman (1997), in his lecture at the Mandel Institute in Israel, spoke enthusiastically about the idea of both teacher communities and student communities. Shulman argued that since a single teacher can never possess perfect knowledge of pedagogical content, we must continue to create conditions in which a teacher can collaborate with other teachers and be part of a community of teachers facing difficult teaching challenges. In other fields, no one expects a single professional working alone to solve an important problem, because complex, real-world problems require "distributed expertise"—the sharing of highly specialized professionals in dealing with common challenges.

Bryk, Gomez and Grunow (2010) identified professional communities, along with a work culture oriented (Markic, et. al., 2016), toward improvement and access to professional development, with elements of "professional capacity" associated with improvements measured in primary school achievement in Chicago over a period of 6 years in the 1990s. A recent study by Kraft and Papay (2014) reinforced this important insight. These researchers used a measure for the professional environment that was composed of the responses of teachers to a survey in North Carolina combined with a national test in mathematics and elementary school reading. They found that teachers who work in a supportive environment, compared to those who work in a less supportive one, have increased effectiveness over time.

PLC workshops for chemistry teachers were initiated in Israel 2 years ago. These workshops were supported by the Ministry of Education and sponsored by the Trump Foundation, the Weizmann Institute of Science, and the National Center of Chemistry Teachers at the Weizmann Institute. The workshop operates on a cascade model: a leading team of researchers guides a group of teachers who will lead communities of teachers in regional communities "professional learning communities close to home" (see Figure 1).

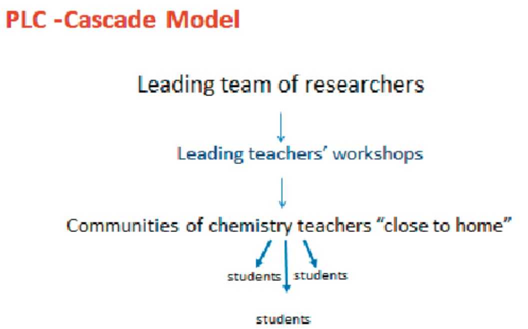

*Figure 1. The PLC cascade model (*Mamlok-Naaman, Eilks, Bodner & Hofstein, 2018)

A leading team of researchers guides a group of teachers who will become leading teachers, and coordinate regional communities of teachers, "Professional learning communities close to home". So far, there are eight regional communities of chemistry teachers in Israel, consisting of Jewish and Arab high school teachers. Each "Professional learning community close to home" is coordinated by two leading teachers who participate in the PLC workshop. The Tira community of chemistry teachers, will serve as an example to a community "close to home".

Tira "Professional learning community close to home"

15 teachers of the "Tira Professional learning community close to home" (TPLCCH), and met once in three weeks, coordinated by 2 leading teachers. Each meeting consisted of:

- An opening activity aimed at creating social and personal relationships among the members of the group, as well as openness and trust to strengthen the cooperation among members of the community, and enable them to gain a sense of ownership
- "Our corner" – one or two teachers share an experiment or an interesting activity with their colleagues—a short, stimulating and thought-provoking activity that can be applied in the classroom. It can be an experiment, a demonstration, a discussion question, an interesting video clip, or a technological innovation in education
- A discussion referring to a content and pedagogical subject, e.g., diagnostic questions, misconceptions, unclear questions, or alternative assessment methods
- Sharing lesson plans regarding new curriculum materials.
- A reflection of each teacher at the end of the meeting, referring to the meeting's topics.

The teachers develop activities and pedagogical teaching strategies with the leading team of researchers (a "bottom-up" approach), and implement them in their own classes before they disseminate them among the communities of teachers in their regions. Following are three examples of major activities

Diagnosis of students' ideas and difficulties.

Teachers are usually surprised to find out that their students have learning difficulties and misconceptions. Therefore, diagnosis of students' misconceptions is a very important activity. During the meetings, the Tira community teachers reflect upon their teaching methods, and discuss how to use different strategies to cope with these difficulties, how to implement the change and then collect and analyze their students' assignments. Major misconceptions have been encountered in topics such as Bonding and structure, Acids and bases, Energy, and Equilibrium.

The following example is based on a study conducted by Ben-Zvi Eylon and Silberstein (1986). The study consisted of three stages: (1) a diagnostic investigation of students' views of structure in chemistry, (2) development and implementation of a program designed to prevent some of the misconceptions identified in the first stage, and (3) an evaluation of the new program. The diagnostic investigation of students' views of structure in chemistry consisted of a questionnaire administered to eleven 10^{th}-grade classes in different high schools in Israel (about 300 students, average age 15 years). All students had studied chemistry for at least half a year. The question relevant to the atomic model was:

A metallic wire has the following properties: (1) conducts electricity, (2) brown color, and (3) malleable. The wire is heated in an evacuated vessel until it evaporates. The resulting gas has the following properties: (4) pungent odor, (5) yellow color, and (6) attacks plastics.

i) Suppose that you could isolate one single atom from the metallic wire.

   Which of the six properties would this atom have?

ii) Suppose that you could isolate one single atom from the gas. Which of the six properties would this atom have?

Most of the teachers at TPLCCH who disseminated this question among their students reported that their students could not differentiate between macro and sub-micro sub-micro concepts. The interventions which they decided upon in order to cope with the misconceptions consisted of: Using models; computerized interactive programs; video clips; games, etc. The process of dealing with the misconceptions which were diagnosed, was based on the Action Research rationale (see below).

Lesson plans referring to sustainable education

A few lesson plans shared at the TPLCCH, dealt with issues of sustainable development, as suggested by the two leaders of the community. Issues of sustainable development have been suggested as a way to contextualize chemistry learning for relevant chemistry education (Eilks and Hofstein, 2014). If this is implemented from an SSI-based perspective (Eilks et al., 2013), controversial issues from the sustainability debate can be used to motivate chemistry learning within the context of a societal perspective. The issue of alternative fuels can be used as an example (Mamlok-Naaman et al., 2015).

In recent years, a group of teachers in Israel developed a lesson plan that was called "Can used oil be the next generation fuel?" (Ezra et al., 2012). This lesson plan focuses students' learning on traditional and alternative fuel sources. The students learn about the advantages and disadvantages of each of the different suggested technologies: fuels from crude oil, recycling of used oils, or producing biodiesel from vegetable oil.

The lesson plan uses a structure that starts with the SSI, involves learning about the content behind the issue, and then turns to questions of evaluation and reflection on the issue from different perspectives and in the foreground of the societal discourse. The lesson plan starts with exposing students to information about the world's energy crisis and its consequences. Discussion of this information activates prior knowledge and raises questions to be answered. The idea that teachers should convey to their students is that sustainable mobility is a worldwide problem and not just a scenario for the science classroom. Furthermore, there are several proposed solutions to this challenge, but these solutions often introduce new problems.

Students undertake different activities to investigate and compare the different fuel types in order to decide on various options for providing fuels for mobility. In one activity, the students are asked to inquire into the chemistry of the use of different fuel types, one of which is biodiesel. Comparative activities require students to select criteria such as enthalpy of combustion values or the release of emissions. The teacher then introduces the student to an experiment that compares the energy released by the combustion of different fuel types. By measuring the mass of the fuel needed to increase the temperature of a certain volume of water by 30 degrees Celsius, students can compare the caloric values of different fuels. They can also investigate the level of pollutants emitted from the burning fuels with a special board called the "Ringelmann scale," which determines the concentration of soot particles produced by the flame. Students are then asked to decide which is the best fuel. Before making a final decision, there is an attempt to involve students emotionally and from an ethical perspective by creating a conflict regarding the use of biodiesel. This activity is based on viewing pictures that highlight the use of crops for fuel instead of using them as a food source for the world's ever-growing population. Students' decisions should be based on arguments, but first there should be agreement within the group about the assumed meaning of the term "best fuel." This discussion leads to understanding that a thorough comparison requires more criteria beyond the limits of chemical behavior. These criteria include price, environmental behavior, production methods, and societal impact. An open discussion about which technology has the most promising potential for sustainable development is used to end this lesson plan.

Within this lesson plan, the students learn about an authentic sustainability issue and the complexity of its solution. On the one hand, they learn that there is no "best fuel" nor any "best solution" to many sustainability problems. On the other, they learn that making use of used oil or biofuels is not "the ideal solution." Other ways might better protect the environment because less waste is produced and fossil resources are saved. However, the students also learn how complex such evaluations are and how many dimensions need to be taken into consideration before an overall decision can be made.

Action Research activities

During the meetings, the teachers at TPLCCH conducted Action Research activities, referring to issues which bothered them. The teachers dealt with content issues as well as pedagogical issues such as: "Can we change students' attitudes toward science by integrating relevant, everyday issues into their science curriculum?" The activities consisted of: (1) identifying the general problem and their own research question, (2) planning the research including the development of the research tools, (3) data collecting and analyzing, (4) implementing, (5) data collecting and analyzing, and (6) evaluating and reflecting. The various stages are presented in Figure 2.

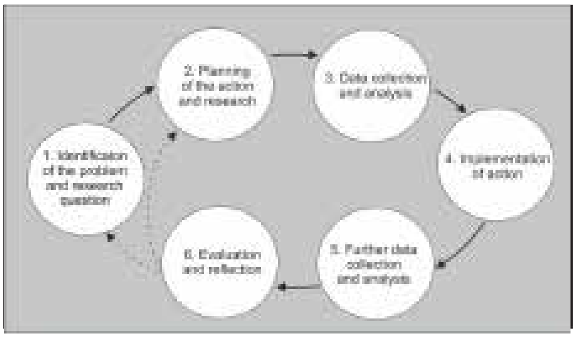

Fig. 2: The various stages of Action Research (Mamlok-Naaman, Eilks, Bodner & Hofstein, 2018)

Action Research is regarded either as a practitioner-oriented inquiry into teachers' work and their students' learning in the classroom (Feldman & Minstrel, 2000) or as the development of new

teaching strategies oriented on teachers' and students' deficits or personal interests (Eilks & Ralle, 2002). According to Feldman (1996), the first goal of action research within such a framework is not to generate new knowledge—whether local or universal—but rather to improve and change classroom practices. Nevertheless, this point may be viewed differently depending on

the action research mode chosen and depending on the objectives negotiated within the group of practitioners and researchers (Eilks & Ralle, 2002). In the end, the development of individual practices and generation of results of general interest can be understood as two sides of the same coin, with both having equal importance.

A further objective of the Action research activities was to enhance the chances of creating a professional community of Chemistry teachers (Mamlok-Naaman & Eilks, 2012). The participants in the Tira community had many opportunities to enhance their social skills through collaboration and cooperation with their peers. They shared ideas, consulted with each other, and maintained good social and professional relations with the others. The PLC meetings enabled them to consult with each other and exchange information and ideas as often as they wished. The cooperation between the teachers in the group was fruitful and helped promote their teaching strategies, as well as their professional development (Laudonia et al., 2015).

Evaluation of the PLC workshop

Data were collected for two years from a variety of sources: Video records of the teacher-leaders' PLC meetings; reflection questionnaires; E-mail correspondences; Interviews; Portfolios; Additional data from questionnaires sent to teachers in the "Professional learning communities close to home", as well as to their students.

The data analysis revealed that the PLC workshops were accompanied by an evaluation study that consisted of questionnaires and interviews. To date, the teachers who have participated in the PLC workshops for chemistry teachers have claimed that the professional community environment improved their self-efficacy and enhanced their ability to share teaching difficulties with their colleagues. The teaching culture improves, as the community increases the degree of cooperation among teachers: trust, ownership, friendship (Tschannen-Moran, 2014). They said that during the meetings, a feeling of trust was developed among the participants, which enabled them to discuss and analyze their students' cognitive and affective problems, misconceptions, and learning outcomes. In addition, the fact that they could share ideas, lesson plans and interesting experiments was an asset in itself. They were encouraged to develop ownership of innovations in education, becoming more student-centered (Mamlok-Naaman, Eilks, Bodner, & Hofstein, 2018).

The PLC community has an impact on teaching practices, and served as a perfect environment for preparing and encouraging teachers to conduct changes - towards gaining pedagogical content knowledge in conveying important issues in education, and preparing the future citizen in a mixed cultural society, focusing on the processes of learning rather than the accumulation of knowledge, in order to enable students to be innovative, creative, and critical.

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Teaching 21st century science with 21st century skills

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Abstract

In many ways the teaching of science at school and university has not changed much over the years and much of the same core content and practical skills are still taught. However, there have been repeated calls from government and industry and other bodies in many countries for students to be proficient also in '21st century skills', as well as in the traditional technical skills associated with science education.

"We live in a fast-changing world, and produciang more of the same knowledge and skills will not suffice to address the challenges of the future. A generation ago, teachers could expect that what they taught would last their students a lifetime. Today, because of rapid economic and social change, schools have to prepare students for jobs that have not yet been created, technologies that have not yet been invented and problems that we don't yet know will arise." (Schleicher, (2010))

These 21st century skills are also referred to as soft skills or transferable skills, and are not specific to science. They include such skills as creativity, critical thinking, problem-solving and teamwork. I want to ask in this article: "Can these skills be taught effectively alongside the traditional content of science courses?" I will argue that they can and that science is an ideal vehicle for developing many of these skills, alongside knowledge of science, scientific literacy and laboratory skills. Such an approach needs to start in secondary school, and is relevant for those students who continue to study science and those who do not. However, it is also vital that the emphasis on 21st century skills continues in university science courses, thus fitting science graduates for the modern work environment. Student teachers also need to be trained to include such 21st century skills in their own science teaching, otherwise they will not become embedded in the educational systems. The inclusion of soft skills alongside traditional skills represents a major change in science education and will need a change in mindset of teachers and students, and in pedagogy, in order to equip students for the future workplace.

Keywords: science education, 21st century skills, technical skills

Introduction

In many ways the teaching of science at school and university has not changed much over the years and much of the same core content and practical skills are still taught. Traditional science teaching, at school or university, still in the main emphasises acquisition of scientific knowledge and concepts, and learning laboratory practical skills. Most of this content and technical skills included in a science course at school haven't changed much in 50 years, although there have been changes in pedagogy. In universities science students encounter the same emphasis on the acquisition of scientific knowledge and concepts, albeit at a higher level, and the mastering of laboratory skills. They may or may not find a change of the way science is taught, and in both school and university the assessment (often terminal and summative) focuses on knowledge and concepts. As a chemistry professor once said: "I tell them, they write it down, and then they give it me back in exams". Too often what passes for teaching is the passage of information from the teacher's notes to the student's notes, without passing through the minds of either of them. If we are honest, that describes our own science education. I have discussed the development of the curriculum in a recent article (Childs, 2015).

Recent discussions of STEM education have been highly critical of the way science has and is being taught in schools, as both a poor preparation for further study but also as poor preparation for work in the 21st century, and so the call has been for STEM subjects to embrace 21st century skills.

"While scientists passionately explore, reason, discover, synthesize, compare, contrast, and connect the dots, students drudgingly memorize, watch, and passively consume. Students are exercising the wrong muscle. An infusion of STEM taught in compelling ways will give students an opportunity to acquire these active learning skills.

The skills of the 21st century need us to create scholars who can link the unlinkable. … Nurturing curious, creative problem solvers who can master the art of figuring things out will make them ready for this unknown brave new world. And that is the best legacy we can possibly leave." (Ramirez, 2013)

There have been repeated calls from government and industry and other bodies in many countries for students to be proficient also in '21st century skills', as well as in the traditional technical skills associated with science education.

"We live in a fast-changing world, and producing more of the same knowledge and skills will not suffice to address the challenges of the future. A generation ago, teachers could expect that what they taught would last their students a lifetime. Today, because of rapid economic and social change, schools have to prepare students for jobs that have not yet been created, technologies that have not yet been invented and problems that we don't yet know will arise." (Schleicher, A., 2010)

This comment was made by the Irish Business and Employers Confederation (IBEC) in August 2018 about the Irish Leaving Certificate examination, the terminal state examination taken at the end of formal schooling.

"The workplace of the future will be very different from that of today, with many of the jobs and skills required for future jobs having not yet been established. Irish business values people with creativity, resilience and aptitude for life-long learning. It is imperative that Ireland's education system equips young people with the skills and knowledge they need to reach their full potential.
"In its current form it is doubtful that the Leaving Cert is in tune with the needs of Irish society and its economy. A high-stakes, terminal exam, predominately based on rote learning and information recall, leaves students with little opportunity to think critically, engage analytical skills and develop greater interpersonal skills.
"It is now time to make the Leaving Cert, and indeed the whole senior cycle and careers service, more relevant for the 21st century. Ibec looks forward to engaging with the National Council for Curriculum and Assessment (NCCA) and other stakeholders on progressing overdue reform.
"To help students transition to future study and into the world of work, we need an education system that encourages a spark for learning, one that creates options for young people and prepares them for the their next phase in life." (McGee, C., 2018)

The problems with science education today

In case you hadn't noticed the world has changed and we have left the industrial age and entered the information (also known as the knowledge age or the digital age.) People have identified a transition from the 3rd industrial revolution to the 4th industrial revolution. However, in many ways education at school and university is still in the industrial age. What we teach (content), how we teach (pedagogy) and how we examine (assessment) have not changed significantly in the last 60 years or so since I left school (Childs, 2015). There is no shortage of research into each of these areas but we are still basically working within the same paradigm, tailored to the industrial age. We have largely failed to adapt teaching and learning to the demands of the information age and are still focusing almost exclusively on content and technical skills. When students leave secondary school at age 18, either for work or further study, they have learned successfully to pass exams but are lacking in soft skills and also in deep understanding even of scientific content and with poorly developed laboratory skills. University academics frequently complain that students are not prepared for advanced study in science: in their science knowledge and understanding; in their practical skills; in their mathematical ability and in their study skills. Many universities now have to play catch-up in each of these areas to allow a more heterogeneous student body to progress. When they graduate they should have a greater and deeper knowledge of science, and be technically proficient in the laboratory, and able to use mathematics in a scientific context. However, their education has still been mostly academic, is focused on technical skills and knowledge, tested by terminal examinations and rarely includes work experience. When students graduate the almost universal response of employers is that they are not properly equipped or prepared or proficient in suitable soft skills (see Tables 1 and 2). Unfortunately we are not living in the 19th or 20th century, when our model of science education was developed, but in the 21st century. Our students are now mostly digital natives, firmly in the 21st century, but many of their teachers and lecturers are still in the 20th century.

What are 21st century skills?

There seems to be broad agreement as to what constitute 21st century skills by educators and industrialists. Here is a list of the most commonly identified skills (see also Table 2).

- Problem-solving
- Critical thinking
- Creativity and imagination
- Data interpretation
- Flexibility
- Collaboration and team work
- Communication skills.

Sometimes, as below, they are summarised as the 4C's or as the 7Cs.

- Communication
- Collaboration
- Critical thinking
- Creativity

Sometimes 3 additional Cs are added:

- Cross-cultural understanding
- Careers and life skills
- Computing and IT skills

Table 1 shows what component skills are associated with each of these seven Cs.

Table 1: The 7 Cs and their component skills

(Adapted from

https://wvde.state.wv.us/instruction/WhyProjectBasedLearningPosting.ppt

ttps://cosee.umaine.edu/files/coseeos/21st_century_skills.pdf)

21st century skill	Component skills
Communication and media literacy	Communicating effectively using a variety of media and forms, creating and analysing messages
Collaboration and teamwork	Working with others to create, use and share knowledge, solutions and innovations, involving cooperation, consensus, compromise
Critical thinking and problem solving	Using HOCS to research, analysis, synthesis, project design and management, decision making
Creativity and innovation	Using knowledge and understanding to create new knowledge, designing solutions to new problems, designing new approaches, storytelling and arts
Cross-cultural understanding	Recognising and respecting diversity and difference, and being flexible and ethical in working with others and in different cultures and settings
Careers and life skills	Developing as self-directed, independent, life-long, flexible learners who are honest, and have integrity and an ethical framework
Computing and IT skills	Effective and ethical use of ICT technology to access, organise, evaluate and share digital information, including visualisation skills

"21st century skills" are the skills that today's students will need to be successful in this ever changing world. The most recognizable of these skills are the 4C's: communication, collaboration, critical thinking and creativity. However, 21st century skills also include social and emotional intelligence, technological literacy and problem solving abilities. These skills emphasize "application of knowledge" and go beyond rote memorization. Now more than ever employers are putting an emphasis on these skills as students are entering the workforce ill prepared. These skills are becoming an important aspect of K-12 curricula. The development of 21st century skills begins in elementary school and progresses up through high school. The need for 21st century skills has spurred the integration of technology along with the emphasis on STEM and PBL in classrooms. These concepts help students develop the higher thinking skills that colleges and employers are looking for. The education industry is changing and placing greater importance on preparing students for the real world, which is why 21st century skills are more important than ever. The definition below from Defined STEM (nd) summarises the need for a change in STEM education.

"Defined STEM utilizes performance tasks, real world videos and project based learning to bring relevancy to the information students are learning. Through these methods of learning students will utilize all 4C's in order to successfully complete their tasks. Furthermore, Defined STEM helps students utilize other aspects of 21st century skills by providing them with digitally based content that emphasizes technological literacy. Through their performance tasks students are asked to use a myriad of skills to complete the assignment at hand. Defined STEM combines multiple subjects into one task and helps the student make real world connections just like they

would have to do in college or their future career. Using this cross curricular approach Defined STEM helps students take learning into their own hands and apply what they have learned to the real world."

(https://app.definedstem.com/21st_century_skills)

The World Economic Forum in a recent report on the Future of Jobs (World Economic Forum, 2016) collected views on the top 10 skills identified by employers in 2015 and in 2020 (Table 2). The lists overlap and differ mainly in the order. The key question is whether our science education is preparing students for the world of work.

Table 2: Top 10 skills needed in 2015 and 2020 (World Economic Forum, 2016, https://www.weforum.org/reports/the-future-of-jobs)

	2015	**2020**
1	Complex problem solving	Complex problem solving
2	Coordinating with others	Critical thinking
3	People management	Creativity
4	Critical thinking	People management
5	Negotiation	Coordinating with others
6	Quality control	Emotional intelligence
7	Service orientation	Judgement and decision making
8	Judgement and decision making	Service orientation
9	Active listening	Negotiation
10	Creativity	Cognitive flexibility

Is it possible to teach science and deliver 21st century skills?

It is clear that the traditional scientific technical skills and knowledge taught in science education fall short of what higher education and employers want to see in future students and employees. It is a common complaint that students leaving school have been trained to pass tests, to regurgitate poorly remembered and incompletely understood facts, but with poor laboratory skills, and lacking in communication skills, creativity and critical thinking. In Ireland, at any rate, this seems to be a perpetual complaint from employers commenting on the terminal school leaving examinations. (McGee, 2018)

Students and parents, and even many teachers, see science as a collection of facts to be learned, standard laboratory procedures to be repeated and routine calculations to be practised. The examinations are predictable and success requires a good memory and lots of practice. The assessment does not encourage real problem solving or creativity and does not require communication skills or data analysis or interpretation. The existing formal examination system does not assess or reward 21st century skills and thus these are not taught and students leave school, and often also university, without them.

What would be needed to change the system to deliver 21st century skills alongside and through science education? For them to be effective the soft skills need to be embedded in the science education, not bolted on from outside, so that students leave with an integrated view of technical and soft skills. When we look at the list of what skills are required (Tables 1 and 2), they are actually the skills needed by a scientific researcher and thus should be compatible with the science curriculum. In fact, science should be the ideal curriculum vehicle for delivering 21st century skills because of the nature of the subject and the fact that it requires cognitive and psychomotor skills, and depends on both mathematics and language as its two supporting pillars. Is it possible to match what we do in science education with what employers look for? Unfortunately, there is often a mismatch between traditional science education and what is required for developing 21st century skills (Table 3).

Table 3: Traditional science teaching and learning approaches compared to teaching and learning for 21st century skills

Traditional	**21st century skills**
Individualistic competition	Group collaboration and cooperation
Learning facts and concepts	Understanding and applying concepts
Focused on LOCS	Focused on developing and using HOCS
Routine recipe tasks and learning practical skills	Open-ended, inquiry tasks applying practical skills
Following instructions and procedures	Devising experimental procedures
Passive learning	Active learning
Single-answer, algorithmic problem solving	Open-ended problems with several answers
No critical thinking	Develops critical thinking

Didactic teaching and one-way (teacher as guru)	Inquiry-based teaching and interactive ((teacher as mentor
Exam-focused and task-focused	Goal-focused and Skills-focused
Summative assessment	Formative assessment

For example, the school and university system often favour and reward individual competition – who is the best student? 21st century skills needed in the workplace, on the other hand, require collaboration, teamwork and cooperation; it's not about passing exams but about achieving goals. Much of what passes for problem solving in science education is just routine, algorithmic exercises rather than real problem solving. Being able to do mole calculations correctly is a skill rarely needed in industry.

Is it possible to match the 21st century skills which employers want with the way science is taught at school (and at university)? In fact, many of the required skills have already been used in teaching and learning science, though not always consistently or comprehensively. For example, employers look for collaboration and teamwork as key requirements of employees. Group work and project work in science can deliver these skills, if they are used consistently throughout a school and university course. Communication skills, written and oral, are vital in industry and there is no reason why these should not be developed through science education. The importance of argumentation and discussion in allowing students to marshal and present evidence and to weigh up opposing views is well recognised. Students need to be given frequent opportunities to practice communication skills in discussion and debate, through producing posters and presentations, by giving talks and writing about science e.g. though creating wikis, magazine articles, poetry etc. All these activities have and are being used in science teaching. Project work, in particular, is a great way to synthesise and apply many 21st century skills within a science context, as the success of science fairs shows e.g. SciFest in Ireland. (www.scifest.ie)

Table 4 shows how 21st century skills and existing science activities can be matched. There are examples in the literature of science education (research and practice) of all of these activities being used and often used effectively, but it is doubtful if anyone is implementing all of them consistently and progressively through a student's educational pathway. Some are more common in school science courses and others in university science courses. Thomas Friedman (2013) has coined a phrase that a student's passion quotient (P.Q.) and curiosity quotient (C.Q.) are better predictors of success that intelligence quotient (I.Q.) (Friedman, 2013).

Table 4: Matching science education activities with 21st century skills

Science teaching activities	**Matching 21st century skills**
Discussion and argumentation; presentations; preparing posters, wikis, articles	Communication skills – oral and written, various media
Projects – lab-based and literature- based; design and build; devising solutions to real life issues; mini companies; IBSE	Creativity and innovation
Group work; group projects; mini companies; jigsaw method	Collaboration and team working
Argumentation; analysis and discussion of media; debate Open-ended problems and inquiry activities; PBL	Critical thinking and problem solving
Using IT in research, presentation and communication; e-portfolios Analysis of experimental and other data; using IT skills and software to analyse and present data	Computing and IT skills Data analysis and interpretation
Visits to industry and scientists from industry; project work; work experience	Careers and life skills
History of science; scientific biographies; philosophy of science	Cross-cultural awareness

Not only is much of science education at all levels failing to develop and incorporate soft skills, but formal traditional education is actually actively destroying them. Creativity falls throughout formal education according to a quantitative study by Land and Jarman of 1,600 American children from 5 (98%) to 15 (12%), compared with adults (2%). (Land and Jarman, 1992)

Sir Ken Robinson has a famous TED talk on 'Do Schools kill Creativity?' (Robinson, 2014), to which question he answers yes. Albert Einstein said: *"It is, in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry; for this delicate little plant, aside from stimulation, stands mainly in* *need of freedom. Without this it goes to wrack and ruin without fail."* An increasing focus on tests and external exams and learning outcomes has narrowed the curriculum and learning experience and resulted in rote learning and memorisation and exam technique. Teaching to the test has resulted in a decline in critical thinking, creativity and other soft skills. The test-based school system favours individual competition over collaboration and cooperation. Student-centred group work and inquiry in primary schools leads to teacher-centred, individual study and didactic teaching in secondary school.

Examples of good practice

It is an educational fallacy that process matters more than content, and skills more than subject matter. As science teachers we believe that content is important, but not the only thing that matters. 21st century skills must be grounded in subject content, as they are the means and vehicle by which students can learn and understand the content and also develop the skills to use and apply their knowledge. The pedagogical methods used in science teaching must be chosen to develop 21st century skills through subject content and classroom and laboratory experiences. Here are some of the key design principles of such a science course:

1. *Connect content knowledge to real world situations and problems so that students experience science as authentic and life-related.*
2. *Emphasise the development of deep understanding though tackling problems and projects and working with others.*
3. *Encourage students to think about their thinking through metacognitive activities and reflection.*
4. *Provide technology to help students access, organise, evaluate and share knowledge and choose suitable ICT tools for specific tasks.*
5. *Allow opportunities for students to become creators and innovators through projects and collaborative activities.*
6. *Engage and stretch students by providing complex and challenging problems that require higher order cognitive skills, access to information and practical skills, and working collaboratively.*
7. *Facilitate collaborative and cooperative work in a variety of contexts and projects.*
8. *Develop career and life-skills by encouraging self-directed and independent learning, making contact with different work environments and enabling relevant work experience.*
9. *Help students develop an ethical framework for decision making and good practice, and help them to become flexible life-long learners, who can make connections with other subjects, concepts, cultures and environments.*(Beers, 2012)

"The keys to integrating 21st century skills into the classroom are application, connections, and participation." Sue Z. Beers (Beers, 2012)

Barriers to change

The way science is taught in many countries in terms of content, pedagogy, assessment and skills does not produce or match the demand of industry and society for 21st century skills relevant to the fourth industrial revolution. To deliver 21st century skills through and with science education requires change: a change in the content, pedagogy, assessment and the pre-service and continuing professional development of science teachers. Change is always difficult and takes time, commitment and resources. There are also barriers to change in the education system and from teachers and parents. The change from a traditional subject knowledge-centred curriculum to learner-centred and skills-centred curriculum is challenging, as this takes many teachers out of their comfort zone and requires changes in pedagogy and assessment, if not in content. The curriculum and assessment are usually centrally controlled and teachers only have control over how they teach. Most teachers and lecturers will have been exposed to traditional science education and may not have experienced or be proficient in soft skills. The following passage describes some of these problems and barriers to change.

"There have been a great many attempts to reform the curriculum, particularly over the last 20 or 30 years. These attempts have mainly focused on making the curriculum more 'learner-centred' – that is, more appealing to - or 'inclusive' of - students from a wider range of backgrounds; more 'relevant' to students' existing experiences, interests and background knowledge; more connected to authentic, 'real world' contexts; and/or more cognisant of what we know about how people actually learn new things. However, while this work (sometimes) resulted in the appearance of new words in official curriculum documents, it has had very little effect on the way science is taught in schools.

Secondary school science programmes largely continue to teach conceptual knowledge in discrete disciplines, while in primary schools science has a low profile, appearing mainly as a topic or context for inquiry learning. The traditional model persists for a number of reasons. Most secondary science teachers support it because their early enculturation through school and undergraduate study has fostered a com-

mitment to and identification with this type of knowledge, and because their existing skills and professional identities are oriented towards the traditional curriculum. It is also maintained by existing resources such as textbooks and laboratories; by school structures such as timetable arrangements and assessment traditions; by many academic scientists and science education academics; and, by the traditional high status conferred on highly differentiated, insulated school subjects like science. The most recent official national curriculum [in New Zealand] provides a number of signals for change and gives schools considerable freedom to make decisions about how it is best implemented in their community: however, these signals are seldom, as yet, being taken up. What all this tells us is that understanding what good science education looks like – that is, science education that is educative, that represents science accurately, and that is engaging for students – is very challenging, and that, despite much effort, it continues to be very challenging." (Gluckmann, 2011, p.25)

We could summarise the main factors which determine the possibility of change towards skills-based teaching and learning as:

- The education (pre-service and in-service) and expectations of science teachers,
- The demands and traditions of the science curriculum,
- The resources used (books and laboratories),
- The teaching methods used,
- The assessment (especially if a formal, national assessment),
- The external demands of higher education, parents, employers and society.

To move towards delivering 21st century skills through school science education will require major change in each of these areas.

Examples of integrating 21st century skills into STEM education

a) **Examples from second level education.**

i) The New Irish junior cycle course

A new Junior cycle course (age 12-15) is being introduced in Ireland based around a set of principles and key skills (Figure 1). The new science specification was started in 2016 and will be examined for the first time in 2019.

Fig. 1: Key skills for the new Irish junior cycle (https://www.ncca.ie/en/junior-cycle/framework-for-junior-cycle)

The important aspect of the new Framework for Junior Cycle is that it aims to integrate subject content with key skills, many of which are 21st century skills. The course also emphasises continuous formative assessment as well as a terminal examination.

ii) **Concept schools in the USA**

Network of 30 schools focusing on STEM (science schools) and integrating 21st century skills into their programmes, as described below.

"STEM education is not the panacea for all the world's problems and this nation's economy, but it is a step in the right direction. In the 30 STEM-focused, college-prep schools in the *Concept Schools* network throughout the Midwest, there is an emphasis on 21st-century skills and strong character development."

(http://www.conceptschools.org/employers-want-stem-skills-and-soft-skills-weve-got-them/)

b) Examples from university (third level) education.

i) RSC transferable skills resources

The Royal Society of Chemistry in the UK has been promoting transferable skills for chemistry graduates for several years as part of their chemistry degree. They have produced a booklet on Key Skills for scientists getting the message across (http://www.rsc.org/learn-chemistry/resource/res00001029/

key-transferable-skills-for-science-students?cm-pid=CMP00001721) and also a downloadable Undergraduate Skills Record (https://www.rsc.org/cpd/undergraduates) for students to fill in during their course.

ii) **University of York YouTube videos**– as part of a module on polymers, students are given an option of making a YouTube video or writing a magazine article. Out of a class of 180 students, 35 chose to make a video. *"When surveyed, these students also fared higher in terms of their ability to recall chemical concepts and scored higher in terms of their engagement with and enjoyment of the course."* (Seijo, 2014)

c) Problem-based learning at University of Reading – using PBL to develop skills for work through a first year undergraduate chemistry module.

"A new first year module was planned with aims to:

- *Introduce students to open and closed types of problems and help them develop strategies for tackling them.*
- *Help students develop independent study skills so they can research a topic, process the information and solve a problem based on it.*
- *Help students develop time management, organisation and team-working skills.*
- *Give students practice and support in written and oral communication and help them develop good scientific writing skills."* (Page, 2013, p. 22)

Recommendations and strategies

Firstly, recognise the importance of 21st century/soft/transferable skills for our students. Secondly integrate the teaching of science at second-level and third-level with the development, consolidation and improvement of soft skills as students progress through the education system and enter the world of work.

Key ways of doing this should include:

a) Group work

b) Project work (individually and in groups)

c) Inquiry-based practical work to develop research skills

d) Opportunities to develop communication skills (written and oral)

e) Frequent use of ICT integrated with other activities

f) Work experience to give real life platform for soft skills

g) Activities to develop critical skills and cognitive acceleration

h) Integrate maths into science teaching including analysis, estimation of errors and presentation of data

One good idea is to create personal e-portfolios summarising student work and achievement and a record of skills development, see the RSC Key Skills for Scientists and the Undergraduate Skills Record (https://www.rsc.org/cpd/undergraduates). A check list of soft skills can be used across modules at third level or across topics and subjects at second level, to ensure that soft skills are covered and revisited throughout a student's career. Project work, either literature-based or lab-based, is ideal for integrating a number of soft skills into a science course and invariably project work enthuses and motivates students.

Conclusion

"Exemplary science education can offer a rich context for developing many 21st-century skills, such as critical thinking, problem solving, and information literacy. These skills not only contribute to a well-prepared workforce of the future but also give all individuals life skills that help them succeed." (NSTA, 2011)

The traditional way that science is taught and assessed, and the way teachers are trained, does not produce, in most cases, students and teachers who are equipped with 21st century skills. As a consequence students are not properly equipped either for further study in science or to enter the workforce in a knowledge economy, which is rapidly moving into the age of the fourth industrial revolution. In many cases we are doing what we've always done and science education in 2018 is not much different in many countries from that in 1968 or even 1918. But the world has changed and is changing faster than the educational system can keep up.

All science education is based on and depends on the 3Rs, without which no progress or real learning can occur: reading writing and mathematics. A useful image that has been developed is the learning equation:

3Rs times 7Cs = 21st century skills

Others have added three further Rs: risk-taking, resilience and reflection and 3Ms motivating, meaningful and made-for everyone. It may become a confusing alphabet soup but the science teacher can recognise the importance of each of these skills and their relevance to science teaching. The challenge is to take what we already know, to implement successful methods and approaches based on science education research, and integrate 21st century skills with our 20th century skills.

This call for 21st century skills is definitely in fashion and in tune with the spirit of the times, but it has also been criticised as being a new setting of an old tune, which many would claim has failed in the past, of process over content, skills over subject knowledge (Ravitch, 2015)

"For the past century, our schools of education have obsessed over critical thinking skills, projects, cooperative learning, experiential learning, and so on. But they have paid precious little attention to the disciplinary knowledge that young people need to make sense of the world.

This deeply ingrained suspicion - hostility, even - towards subject matter is the single most significant reason for the failure of the standards movement in American education over the past generation.

We should have been educating future teachers to study their subject or subjects in depth. We should have paid attention to what Lee Shulman, educational psychologist and professor emeritus at Stanford, calls "pedagogical content knowledge." We should have been helping teachers determine ways to light up young minds and to generate excitement about historical imagination or scientific discovery."

I would agree that as scientists and science teachers, our subject is of paramount importance. I am **not** saying that we should favour process over content, or soft skills over technical skills, or theory over practical work; what I am saying is that we should modify our pedagogy and our assessment so as to build soft skills into our teaching of science. The result will be that our students come out of school or university more employable, with a broader set of skills than just being technically competent. Our aim must be high quality STEM education **together with** embedded and integrated soft skills. As we live in the knowledge and digital age and enter the fourth industrial revolution, we do our students a disservice if we do not allow them to develop 21st century skills alongside their technical skills. They need, society needs and their employers need excellence in both of these areas. This extract on '21st Century Skills: Preparing Students for THEIR Future' is a good summary of where we should be heading.

"Instruction that meets the needs of today's students will incorporate:

- *A variety of learning opportunities and activities*
- *The use of appropriate technology tools to accomplish learning goals*
- *Project- and problem-based learning*
- *Cross-curricular connections*
- *A focus on inquiry and the student-led investigations*
- *Collaborative learning environments, both within and beyond the classroom*
- *High levels of visualization and the use of visuals to increase understanding*
- *Frequent, formative assessments including the use of self-assessment.*

The role of teachers in a 21st century classroom shifts from that of the "expert" to that of the "facilitator." The focus for instruction shifts from "knowing" to being able to use and apply information in relevant ways. Students who are being prepared for the 21st century will be involved in "continuous cycles of learning" (Lemke, et al, 2003) that lead to deeper understanding of the subject area content and that develop the critical skills for meeting the challenges of the future." (Beers, 2012)

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Sustainability as a Foundation for Accessible and Relevant Science Education

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Abstract

By considering the concepts of green chemistry and sustainability in laboratory experiment design, we can provide a safer and more engaging experience in the teaching laboratory. Combining this approach with awareness and understanding of local circumstances is an effective way to provide both accessibility and relevance in the science curriculum. This paper reports initial steps toward the development of teaching materials for K-12 science based on the Traditional Knowledge of Indigenous peoples.

Keywords: Accessible experimentation, green chemistry, relevant science, Traditional knowledge, Indigenous science

Introduction

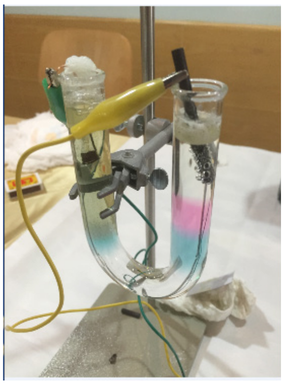
Introduction of the concepts of green chemistry and sustainability in the instructional laboratory represents a remarkable opportunity to provide students with a safe and engaging experience in the practice of modern chemistry. By providing students with valuable knowledge about the intrinsic hazards of chemistry and ways to recognize and reduce or eliminate these hazards, we have the opportunity to train the next generation of chemists and chemical users to make smarter, more-informed decisions.

A commonly heard objection to a "green" teaching laboratory is that it will not train students to work with the hazardous materials for which chemistry has deservedly gained its bad reputation. However, the vast majority of students enrolling in our chemistry laboratory courses have no intention of becoming chemists, but rather are fulfilling requirements for pursuit of medical, pharmaceutical, dental, or other professions. Most of these students will not work with hazardous chemicals, and they can learn proper, modern laboratory techniques without risking their health or that of their classmates and teachers. Further, by including discussions of chemical hazards and toxicity, we can better educate these non-chemists about how to recognize chemical hazards when they do arise, helping them to adopt safer practices. As but one example, perhaps this education will lead to the phasing out of volatile and reactive alkyl halides in dentistry, a practice dating back to the first reported use of ethyl bromide as an anesthetic in 1849 (Long, 1903) but continued in the present time with the use of ethyl chloride for assaying pulp vitality and cold-sensitivity (Chen, 2009).

Since the formal introduction of the concepts of green chemistry (Anastas, 2000), educators have developed and disseminated numerous teaching experiments that provide a rich variety of investigations to enhance student learning of traditional topics while also introducing both more modern topics (*e.g.*, palladium catalysis) and the essentials of green chemical thinking (see, *e.g.*, Dicks, 2011; Doxsee, 2003; Henrie, 2015; Roesky, 2008). Unfortunately, most of these investigations require chemicals and equipment that are unavailable in most schools, particularly in underserved and impoverished regions. In laboratory workshops around the world, participants have often "hoarded" any chemicals that were provided in order to have the opportunity to demonstrate the investigation, if only once, for their students. In addition, participants tend to avoid experiments requiring special equipment – even things that are taken for granted in many institutions – as they see no reason to learn how to do something they will simply never be able to replicate at their home institutions.

This situation arose in a Latin American workshop, where an otherwise popular experiment (Warner, 2002) attracted little attention due to the requirement for a rotary evaporator. My students and I continued to work on this experiment and found that it could be performed more simply and safely while avoiding the need for a rotary evaporator (Young, 2011). This experience represented a turning point in my career. Recognizing that simply bringing our developments to teachers throughout the world would not be effective, my focus turned to developing investigations using locally available materials. Not only does this immediately make the experimentation possible, but by exploiting local materials, it also provides relevance (Mpofu, 2014). This matter of relevance is critically important (Sjøberg, 2005), and it is no less true in more prosperous institutions. When I replaced our traditional steam distillation of clove oil with peppermint, for example, roughly 15% of my students reported that they were either members of or familiar with families with connections to Oregon's regional peppermint oil industry, and the experiment was far more meaningful to them.

Two educators were particularly influential as I turned to the development of locally relevant and accessible experimentation. Muhamad Hugerat, of the Arab Academic College for Education in Haifa, inspired me by his creative use of inexpensive materials to teach chemistry to younger children. One of his experiments, the electrolysis of brine coupled with reactions of unsaturated plant oils (Basheer, 2006), is particularly rich in chemical content that is easily adaptable for students ranging from young children through the university level. In a workshop at Assumption College – Thonburi, Thailand, I introduced an additional layer of complexity by adding a blue-pigmented flower extract to the electrolysis solution, allowing for visualization of local pH as well as the coupled chemical reactions of olive oil (saponification at one electrode and chlorination at the other).



Electrolysis of butterfly pea (*Clitoria ternatea*) extract (Doxsee, 2018)

Peter Schwarz (Alexander-von-Humboldt Hochschule, Germany) further inspired my work through his creative adaptation of trash – drug ampoules, juice containers, and plastic water bottle, *inter alia* – for use as experimental apparatus (Schwarz, 2006).

My most recent work has been in Madagascar, generally ranked as one of the ten most impoverished nations on Earth. In the rural countryside, children may walk great distances to get to a school where, if they are lucky, there may be a desk for them. This inaccessibility, coupled with unaffordability and a lack of relevance to their rural lives, leads to poor attendance and early withdrawal from school, despite government-mandated compulsory education through age fourteen (World Bank, 2008).

Madagascar is littered with the remnants of humanitarian efforts gone awry. The typical model of bringing something to the people, then leaving them to fend for themselves, is destined to failure, differing little, in principle, from the impacts of French colonization and later departure. Without local engagement at the beginning of a project, and without recruitment and training of local experts, the "good" that is done, be it installation of wells to provide clean water by a humanitarian group or the construction of railroads by the French, inevitably evaporates as soon as the installed systems fall into disrepair with no one able to fix them.

Inspecting the single functional water pump found during a recent visit (vicinity of Manakara, Madagascar, 2017)

A typical railroad remnant (Madagascar, 2017)

What Madagascar does have is a population of warm and remarkable people and an abundance of natural resources that may be used for scientific investigation. Fruits and vegetables, flowers, and spices (note the cloves – *Syzygium aromaticum* – drying along the railroad tracks in the above image) all offer rich opportunities for experimentation.

Children in the village of Ankevohevo, Madagascar (2017)

Madagascar is rich in minerals, including iron (the presence of which has led to Madagascar being referred to as the Red Island), and metalworking is practiced in many parts of the country; these represent additional opportunities for experimentation. Accustomed to subsistence living, the Malagasy people are remarkably ingenious when it comes to making and repairing things – a broken drive train on a truck days away from the nearest repair shop demands creative solutions – so the construction of simple lab ware for carrying out experimentation, if required, will present no obstacles.

As I enter a new community, I seek to create an inventory of local resources and industries while also learning about the educational expectations of students, parents, teachers, and government. Coupling this information with an understanding of Indigenous cultures and traditions that represent opportunities of linkages to science content, we are then equipped to collaboratively consider ways in which to connect the intrinsic science of local traditions, resources, and industries to their educational expectations (Mack, 2012; Ryan, 2008).

Recently, I had the opportunity to teach a new undergraduate class, *Science Education in Remote and Rural Locations*, in which we applied my experiences in Madagascar and elsewhere to the development of science education materials for use in Native-serving institutions in the United States. In the following section, I present an overview of that class and highlight several of the resultant student work products.

Results and Discussion

The key lessons from my curriculum development leading up to this class offering were to recognize local limitations and embrace them as challenges, to exploit locally available materials in order to develop locally relevant content, and, ideally, to engage local teachers and students in the effort. These lessons led me to present five primary objectives for the class, as briefly discussed in the following paragraphs.

Objective One: Gain an operational understanding of Native-serving K-12 institutions in the Pacific Northwest. There would clearly be no point in even talking about curriculum design without gaining perspective on what educational requirements, expectations, and challenges must be met. The superintendent of the oldest continuously operating Indian Boarding School in the U.S. and one of her students led a fascinating discussion about the current realities in their school. This proved to be a remarkably emotional introduction to the class, as students learned about the history of Native American displacement and enrollment in so-called Indian Boarding Schools, where the primary objectives were to erase Native culture and assimilate Natives into white American society. Asked about her future plans, the student awed the class when she stated that she was going to become a neuroscientist, then return to her reservation to help her people.

Objective Two: Develop working familiarity with the core concepts of the U.S. Next Generation Science Standards (NGSS, n.d). This set of standards defines educational milestones and expectations at schools in most of the United States, including Native-serving institutions, beginning with the enunciation of a useful set of science and engineering practices.

1. Asking questions (for science) and defining problems (for engineering)
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations (for science) and designing solutions (for engineering)
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

I felt it was important for my students to have some familiarity with these standards, though I did not want the standards to limit their creativity in designing new materials for science education. Thus, in their independent projects, described under Objective Five below, I encouraged students to consider how their proposed experimental investigations might be fit into the NGSS framework rather than letting the framework dictate the types of experiments they might propose. We also discussed the creation of lesson plans and unit plans, things that the students had implicitly experienced but for which they had no practical experience in creating (Cunningham, 2009).

Objective Three: Develop an understanding of Traditional Knowledge and modern science as complementary ways of knowing. Both implicitly and explicitly, non-Natives tend to view Traditional Knowledge, which typically passes orally from generation to generation, as myth and fantasy (see, *e.g.*, Sepie, 2017). After sharing a short story about an Eskimo hunter using "an old technique of mimicking a seal" to hunt polar bears (ANSC, 2018), I challenged the class with the question, "Is this science?" After a moment of uncomfortable silence, the students rose to the challenge and engaged in a discussion of what "science" means. In the process, they recognized numerous similarities between the Traditional Knowledge illustrated by the story of the Eskimo hunter and what we came to call, for lack of a better term, "Western science." Both rely heavily on repetitive observations, the recognition of patterns, and the creation, testing, and revision of hypotheses. Yet, they clearly differ as well. Most importantly, Traditional Knowledge is "place based" (see, *e.g.*, Nalau, 2018). It does not seek to explain universal things, but rather addresses local matters. While it is thus both contextual and "particularistic," it can offer unanticipated and more generally applicable insights that offer promise of "Darwinian" technological advances (Elster, 1983). Traditional Norwegian fishing boat design, for example, does not fit modern models, yet study of their "primitive" design revealed that they were hydrodynamically sound and actually performed better than conventional designs under locally dictated conditions (Elster, 1983; Føllesdal, 2002).

Thus, Traditional Knowledge and Western science offer complementary "ways of knowing" (Aikenhead, 2011; Dunkel, 2018). Interestingly, while Western science represents a single, global way of knowing, each of the world's myriad Indigenous communities has its own place-based system of knowing (Barnhardt, 2005). Our discussion led naturally to consideration of other ways of knowing – faith, emotion, language, *etc.* (TOK, 2008). We concluded with a very lively consideration of "ways of *not* knowing," including both literal denial, "the assertion that something did not happen or is not true," and interpretive denial, in which basic facts "are given a different meaning from what seems apparent to others" (Cohen, 2001).

Dreaming often plays a key role in Traditional Knowledge (Irwin, 1996), perhaps adding to our "Western" sense of disbelief in the validity of this form of knowing. However, students readily admitted to frequently having important and creative thoughts while in a dream-like state, and most scientists are well aware of the stories of Kekulé, Bohr, and Mendeleev, all of whom professed to have gained breakthrough insights while dreaming.

Objective Four: Recognize the complex interpersonal and intercultural dynamics and sensitivities of scholarship in Traditional Knowledge and Traditional Ecological Knowledge. With a lengthy history of oppression, attempted assimilation, and appropriation of land, culture, and intellectual property, it should not be surprising that a non-Native must earn the opportunity to partner with Native Americans in this endeavor. "We don't care what you know until we know that you care" is a regularly heard sentiment.

Traditional Knowledge has always been closely guarded by its owners, and this wariness about sharing knowledge with non-Natives is exacerbated by intrinsic Native and non-Native views regarding ownership. While Native peoples believe the Earth belongs to all, non-Natives seek ownership of "intellectual property," and there are sadly numerous examples of non-Native attempts to patent, control, and exploit resources long utilized by Native peoples (Hansen, 2003).

Nor are we helped by the commonly encountered efforts by Western scientists to *validate* Traditional Knowledge, a well-meaning but misguided effort given that that Traditional Knowledge was developed over centuries, perhaps millennia of observation, testing and revision. If the Yakama people harvest camas (*Camassia quamash*) a certain way, at a particular time of the year and using a specially-designed tool, there is no need for "science" to validate this knowledge; if there were a better way to accomplish this task, *that* technique would be used! Similarly, if a particular herb is used to treat an illness, one can be certain that the herb contains something that is effective against that illness, for if not, a different herb would have been put to that task. Rather than providing validation of Traditional Knowledge, Western science might more appropriately be recognized as slowly catching up with the Traditional Knowledge developed over the past millennia (Nicholas, 2018).

Objective Five: Develop the ability to propose, research, analyze, and discuss experimental investigations related to various topics within the context of Traditional Knowledge. Synthesizing all their prior learning, students completed a term project, through which I asked them to link Traditional Knowledge, as expressed in Native stories, with "Western science" in order to represent the complementarity of these two different ways of knowing. In addition to relating the essence of their chosen stories, I asked them to identify connections to Western science, particularly looking for cross-cutting themes integrating multiple fields of study, and, most importantly, to propose ideas for hands-on experimentation relevant to their chosen themes, ideally with minimal requirements for materials.

Given the confines of this initial 10-week course, we experimented with using Native stories available in the published literature as our sources of Traditional Knowledge. I discussed this approach with Native partners, recognizing that use of written stories when these stories have *always* been orally transmitted presents numerous potential problems. Who told the story, to whom, when, and in what language? What biases, implicit or explicit, were introduced in the processes of listening, translating, and transcribing? A story recorded by a Native Elder would most certainly differ greatly from that transcribed by a religious missionary during a time of forced assimilation. Indeed, a local Elder in Residence at the University of Oregon suggested that if students heard an authentic telling of one of the stories they read, they would likely not even recognize it as the same story. While in the longer term, it will be essential to engage directly with Native communities and storytellers, the class did learn a great deal by placing their chosen stories in the context of their sources and the possible "lenses" through which they may have been heard and recorded.

I offered students the choice of either reading an assortment of Native stories to find inspiration or selecting a topic of interest and then seeking Native stories that appeared to be relevant to that topic. While each of the nineteen students chose the first approach, they developed a remarkable range of materials, covering topics throughout the life, physical, and environmental sciences. In the following paragraphs, I present the highlights of three student work products, chosen to illustrate both the topical diversity and the great creativity with which students engaged with this assignment.

The Sacred Coyote and its Ecosystem. The coyote, a wolf-like animal indigenous to much of North America, features prominently in numerous Native stories, often playing the role of a wily "trickster" but also playing more positive roles, guided by his wisdom and cunning (see, *e.g.*, Linderman, 1996). One student, Aviva Kaye-Diamond (majoring in political science and Spanish) introduced Coyote through a creation legend of the Okanagan people (spanning what is now called the state of Washington and part of Canada), in which Coyote teaches the people "the best way to do things and the best way to make things" (Clark, 2003). As Ms. Kaye-Diamond noted, the story was related in written form by Ella Clark, a non-Native who based her version on colonial-era work, but supplemented by numerous interviews with Natives. Following this introduction, Ms. Kaye-Diamond presented a range of learning activities directed toward introduction of the concept of ecosystems at the elementary school (fifth grade) level. Her lesson plans included discrete learning outcomes, both cultural and scientific, grounded in contemporary pedagogical research, and covering a range of crosscutting concepts. These learning outcomes noted that, by the end of the lesson, students would be able to:

- Describe their own personal and cultural connection to the natural environment (Emmons, 2014),
- Self-reflect on their own culture, whether it be "Western," Native, or something else (Holland, 1992), and
- Map and list basic ecosystems and conservation principles

In a service to teachers still struggling with the implementation of the Next Generation Science Standards, Ms. Kaye-Diamond concluded by linking the lesson to those standards met by the lesson (NGSS, 2018).

- Ecosystem Dynamics, Functioning, and Resilience (3-LS2.C)
- Adaptation (3-LS4.C)
- Ecosystems: Interactions, Energy, and Dynamics (5-LS2)
- Interdependent Relationships in Ecosystems (5-LS2.A)

Volcanoes. A second student, Mr. Adam Herbers (majoring in mathematics and economics), used Pacific Northwest and Hawaiian Native stories to introduce geological details of volcanoes. Clarence Bagley, a non-Native historian working during the late 1800s and early 1900s, recounted a Klickitat peoples' story of Loowit, whose transformation "into a beautiful maiden" led to a violent battle between two brothers, Wiyeast and Klickitat (Bagley, 1930). Mr. Herbers drew a connection between this violent battle and the cataclysmic eruptions of the stratovolcanoes found throughout the Pacific Northwest of North America, the homeland of the Klickitat peoples and other tribes that share similar stories. Hawaiian legend, in contrast, relates the slow burning and lingering anger of Pele, the goddess of fire, in retribution for her murder (Volcano World, n.d). This simmering rage, as Mr. Herbers creatively deduced, captures the essence of the virtually continuous, slow eruptions of Hawaii's shield volcanoes.

Ways of Seeing. Ms. Casey Bisted, a chemistry major, developed a remarkably comprehensive set of lesson plans around the general theme of "ways of seeing," a concept of seemingly universal importance in Native stories from throughout the North American continent. Her connection of a Native story she heard from a Wasco Elder (the Wasco are a tribe located in the Pacific Northwest) to various age-appropriate topics in physical science was nothing short of inspired! I might have expected her to make "obvious" connections to seeing, based on clearly relevant stories like the Nlha7kápmx legend, Coyote Visits his Daughter in the North (Hanna, 1996).

"Finally there were these little red berries ... - the kinnikinnick berries. Those berries, they tried in her eyes, 'My god, I can see!'"

Kinnikinnick is an indigenous plant common in the Pacific Northwest, and one could imagine proposing various scientific investigations of it – cultivation of the plant from seed and examination of the properties and components of its red berries, for example. Or, one could go a step further, noting that kinnikinnick leaves have been dried and smoked for their potentially hallucinogenic properties (Mariott, 2010), taking the concept of "seeing" to the next level. Ms. Bisted, however, was far more creative! Her Wasco story told of a small mouse who gave his eyes to an older, blind mouse. Blind himself as a result, the mouse was grabbed by a hawk and taken high into the sky, where he first felt the light of the sun, then turned into a falcon and saw as no mouse had seen before.

Ms. Bisted titled her lesson plan, "Viewing Things in a Different Light." For younger (elementary school) students, Ms. Bisted suggested drawing from the small mouse's decision to give up his eyes, which he did only after considerable introspection. Noting that self-examination is most often done with a mirror, she proposed simple experiments with mirrors, illustrating the ray-like properties of light and some elementary optics. For middle school students, Ms. Bisted suggested a connection to the small mouse's examination of the blind mouse, which he at first detested but then came to respect by viewing him in a different way. As another way of seeing things "as no mouse has seen before," she presented the construction and exploration of a simple, pinhole camera (Instructables, 2012). Finally, and even more creatively, for high school students, Ms. Bisted drew from the small mouse's being brought into the sky by the hawk to introduce the concepts of spectroscopy, a set of techniques developed around the principle of excitation into a higher-energy state. In this lesson, she directed students through the creation of a simple spectroscope, using a compact disk as a diffraction grating, and a set of guided investigations using this homemade spectroscope (Redd, 2013; RSC, 2018; Turricchia, n.d).

Conclusion

The Traditional Knowledge of Indigenous peoples, transmitted from generation to generation through the oral tradition, represents a valuable resource for science education. Drawing from this knowledge, based on centuries of observation and experimentation, in the classroom provides the opportunity for discussions and hands-on exploration of science that are both accessible and relevant. This approach to curriculum development, while presented here in the context of Native education in the Pacific Northwest of the United States, is equally applicable to other communities throughout the world.

Acknowledgments

An edited compilation of the complete body of student reports will be distributed to our many Tribal partners as a sign of respect for their wisdom and assurance that we recognize that this knowledge and wisdom belong to them.

The University of Oregon was established on Kalapuya Illahee – the traditional Indigenous homeland of Kalapuya peoples, who were dispossessed of their Indigenous homeland by the U.S. Government over several years, but most notably in Treaties between 1851 and 1855. Kalapuya people were forcibly removed to what are now the Grand Ronde and Siletz reservations, and are now members of the Confederated Tribes of the Grand Ronde Community of Oregon and the Confederated Tribes of Siletz Indians. I share this information out of humility and respect for this Indigenous homeland, and for the peoples who continue to live and thrive in what is now called the State of Oregon.

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Designing Science Education Learning Environment to Engage Students in Developing Useable Knowledge

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Abstract
How should science learning environments be designed to focus on knowledge-in-use standards where learners use the big ideas of science and scientific practices in conjunction with crosscutting concepts to make sense of phenomena and solve problems? Investigating questions that students find meaningful has long been supported as a viable learning structure. Project-based Learning (PBL) structures science learning environments around questions that engage students in collaborative inquiry. In the process of finding solution to the questions, students learn important scientific ideas and practices, crosscutting concepts, and 21st century skills. Because PBL focuses on students and their interests, it is sensitive to the varied needs of diverse students with respect to culture, race, and gender. In the presentation, Professor Krajcik will explain the features of project-based learning and show how the various features of PBL are anchored in what is known about how students learn.
Project-based learning uses a question anchored in phenomena or problems that are meaningful to learners. This question drives student exploration and learning. Establishing the *driving question* sets the stage for meeting all of the other key features of PBL. The driving question focuses students planning and carrying out collaborative investigations and guides the development of artifacts. We conceptualize artifacts as concrete representations that results from students' investigations. As students collaboratively pursue solutions to the driving question, they develop useable knowledge and 21st century skills necessary to solve problem, make sense of phenomena and learn more when needed outside the classroom.
Keywords: Project-based learning, knowledge-in-use, engagement, 3-dimensional learning.

Introduction
Supporting students in developing knowledge that they can use does not occur simply by passively accumulating knowledge, but by using and applying knowledge as the individual engages in

Disciplinary activity (Pellegrino & Hilton, 2012). We refer to this as knowledge-in-use. This knowledge-use perspective has gained prominence in the United States with the Next

Generation Science Standards (NGSS; NGSS Lead States, 2013). The NGSS address science and engineering design,
and includes goals that call for students to actively participate in the authentic practices of the disciplines. The emphasis on knowledge-in-use reflects an increased awareness by educators, policymakers, and the public of the proficiencies required by people to participate as global citizens in the 21st Century.

How do we develop learning environments to support learners in developing knowledge-in-use? How can researchers and teachers develop science learning environments to focus on knowledge-in-use where learners use the disciplinary core ideas, crosscutting concepts and science and scientific practices to make sense of phenomena and solve problems? Research from learning sciences (NRC, 2007, 2018; Sawyer, 2014) supports the design of learning environments that engage students in authentic contexts where they find design solutions to complex problems and make sense of phenomena by using disciplinary ideas, crosscutting concepts and scientific and engineering practices.
The Crafting Engagement in Science Environments (CESE) project has taken up the challenge of designing engaging learning environments for high school physics and chemistry to improve science achievement, engagement and social and emotional learning experiences in high school science learning (Schneider, Krajcik, Lavonen, Salmela-Aro, in press). Our challenge in CESE is building learning environments that:

- Foster deep, integrated and useable understanding of important scientific ideas and crosscutting concepts
- Engage students, i.e., create optimal learning environments, in learning science
- Support students in developing important scientific practices and 21st cen-

tury competencies

- Support students to solve problems, think critically and innovatively

In this manuscript, we describe our design principles and share an example of preliminary findings in one classroom.

New vision of science learning**:** The Framework for K- 12 Science Education (NRC, 2012) as well as a recently released consensus study from the NRC (2018), *Science and Engineering for Grades 6-12: Investigation and Design at the Center* (2018), presents a new vision for science education that moves classroom teaching away from the presentation of numerous disconnected science concepts to learning environments where students use the three dimensions of scientific knowledge: disciplinary core ideas (DCIs), science and engineering practices, and crosscutting concepts, to make sense of real-world phenomena or design solutions to problems. This new vision promotes students using the three dimensions of scientific knowledge – disciplinary core ideas, scientific and engineering practices, and crosscutting concepts– to support students in making sense of phenomena and finding solutions to problems. Although each of the dimensions is important on its own to make sense of phenomena or solve problems each dimension works together to support students in the process. This knowledge-in-use perspective presents a significant change in what science teaching and learning should look like. This integration of the three dimensions is referred to as three-dimensional learning (3D-learning).

***Features of Project-based* learning:** Our design approach focuses on designing project-based learning environments. Project-based learning can support students in 3D-learning and building knowledge-in-use. Project-based Learning (PBL) structures science learning environments around questions that engage students in collaborative inquiry. In the process of finding solution to the questions, students learn important scientific ideas, crosscutting concepts and practices, and 21st century skills. Because PBL focuses on students and their interests, it is sensitive to the varied needs of diverse students with respect to culture, race, and gender. Table 1 presents an overview of the major features of project-based learning (Krajcik and Shin, 2012; Krajcik and Czerniak, 2018).

Table 1: Features of Project-based Learning
Meet important learning goals (NGSS performance expectations- PE)
Pursue solution to ***meaningful questions***
Explore the question by participating in authentic, situated inquiry to **"figure out**" why phenomena occur
Engage in **collaborative activities** to find solutions
Use learning tools and other **scaffolds** to help students participate in activities normally beyond their ability
Create **artifacts** – tangible products – that address the driving question

Project-based learning uses a question anchored in phenomena or real-world problems that are meaningful to learners. This question drives student exploration and learning. Establishing the *driving question* sets the stage for meeting all of the other key features of PBL and supporting learners in developing knowledge-in-use. The driving question focuses students' planning and carrying out collaborative investigations and guides the development of artifacts, concrete representations of the results of students' investigations. Throughout PBL students collaborate and use cognitive tools in their investigations and in building artifacts. As students collaboratively pursue solutions to the driving question, they develop useable knowledge and 21st century skills necessary to solve problem, make sense of phenomena and learn more when needed. PBL presents a different vision of the science classroom; one in which students wonder about and ask questions about phenomena and then investigate and collaborate with others to find solutions and responses to their questions. They also explore various solutions to problems. Students design and carry out investigations, analyze and interpret data, construct models, design solutions and scientific explanation, collaborate, and produce artifacts to show what they have learned. As such, the PBL classroom is a sense-making and knowledge-generating environment.

Our goal in designing and testing PBL curriculum is to create optimal learning environments that will peak students' interests and drive them to learn (Schneider, et al., 2016). Picking phenomena and corresponding driving questions that will drive student learning is thus an essential aspect of our work. Table 2 presents key features of driving questions (Krajcik & Czerniak, 2018).

Table 2: Key Features of Driving Questions
Sense of Wonder
· The driving question creates a need to know
· The driving question is broad enough to allow students to ask their own questions
Feasible
• Students can design an investigation to answer the question.
• Students can perform an investigation to answer the question.

Worthwhile
• The question is related to what scientists really do.
• The question is rich in science content/concepts.
• The question is complex enough to be broken down into smaller questions.
• The question leads to further questions.

Contextualization
• question is anchored in real world issues.
• The question has real world consequences.
• The question is interesting and important to learners.
• The question intersects with learners' lives, reality, and culture.

Ethical
• The practices used to answer the question do not harm living organisms or the environment's sustainability.

Sustainable
• The question allows students to pursue solutions over time.
• Encourages students to explore ideas in great detail.

PBL pushes learners to engage in the figuring out process to make sense of phenomena. The figuring out process has four major steps:
1. Learners experience a phenomenon: Events in nature that students can observe and investigate.
2. Learners can ask questions about the phenomena: Students can ask their own questions.
3. Students use disciplinary knowledge, crosscutting concepts and scientific practices to make sense of phenomena.
4. Students figure something new about the phenomena and ask new questions.
As learners explore solutions to questions to make sense of phenomena they engage in various scientific and engineering practices and use crosscutting concepts. Table 3 presents a summary of the scientific and engineering practices.

Table 3: Scientific and Engineering Practices (NRC, 2012)
· Asking questions (for science) and defining problems (for engineering): Students ask questions about phenomena or to define a problem. Their questions are driven by curiosity. The answers to scientific questions provide explanations supported by empirical evidence.
· Developing and using models: In science, models explain and predict phenomena. In engineering, models provide prototypes of solutions to problems.
· Planning and carrying out investigations: Scientific investigations provide data to support claims about how phenomena work. Engineering investigations test to see if solutions provide intended results.
• Analyzing and interpreting data: Presenting and analyzing data in various ways reveal patterns and relationships.
• Using mathematical and computational thinking: Mathematical thinking is key to making sense of phenomena. Computational thinking helps to find repeated patterns and in creating sequence.
• Constructing explanations (for science) and designing solutions (for engineering): Explanation relates one variable to other variables and provides the how and why a phenomenon occurs. Designing solutions includes generating, testing, and revising solutions.
• Engaging in argument from evidence: Argumentation involves reaching decisions about why phenomena occur and the best possible solutions. Both involve the use of evidence and reasoning.
• Obtaining, evaluating, and communicating information: In science, it is essential to be able to read critically to obtain information and judge the validity and reliability of that information. As important, presenting one's ideas supported by evidence and reasoning is critical.

Table 4 presents a summary of the crosscutting concepts (NRC, 2012).

Table 4: Crosscutting Concepts (NRC, 2012)
1. Patterns: Scientists make observations of phenomena to determine patterns that will guide organization and classification and prompt questions about relationships and the factors that influence the observed patterns.
2. Cause and effect: All events have causes and outcomes. A major activity of science is determining causal relationships and the mechanisms to explain phenomena.
3. Scale, proportion, and quantity: Phenomena occur at different scales in terms of size, time, and energy. Changes in scale, proportion, or quantity affect the behavior of phenomena.
4. Systems and system models: Scientists always define the system they are exploring by specifying its boundaries. Developing a model of the system provides tools for understanding and testing ideas about the system.
5. Energy and matter: Flows, cycles, and conservation. Tracking the flow of energy and matter into, out of, and within systems is essential in building an understanding of the system.
6. Structure and function: The structure of an object or living thing determines its properties and

functions.
7. Stability and change: Scientists study how and why a system changes and what causes that system to be stable or change.
The use of the driving question and phenomena to engage learners is based upon developing optimal learning moments to promote deep engagement and learning (Csikszentmihalyi, 2008, Schneider, et al. 2018). These optimal learning moments occur as a result of domain specific engagement experiences in which learners are deeply engrossed in a task because of the situation. Three conditions are necessary for this domain specific engagement:
• Situational and domain specific interest that drives motivation.
• Necessary skill required to complete a task
• Challenging situations that emphasize learning new knowledge (but not too challenging to hinder new learning).
The figuring out process provides situational and domain specific interest. Using the practices in combination with crosscutting concepts and disciplinary core ideas require certain skills or capabilities from students – how to build a model, design an investigation or argue from evidence. The figuring out process also requires a level of challenge for the learners that is within their reach.

Methods
Our materials design process: We use the following design process to design the materials. The process is modified from our previous design work (Krajcik, Codere et al. 2014, Krajcik, McNeill and Reiser, 2008 and Shin, Stevens and Krajcik, 2007). We begin by selecting NGSS performance expectations that work together – a bundle - to promote proficiency in using the ideas expressed. We next examine and unpack the disciplinary core idea(s), practices, and crosscutting concepts in the selected PEs. Think of unpacking as a process of determining which ideas are critical for the learner to understand. Unpacking involves breaking apart and expanding the various science ideas to elaborate the various disciplinary content ideas. We ask: What science ideas need to be developed? What science ideas will students need to know? What must students be able to do? In so doing, we take into consideration prior performance expectations that serve as the foundation for the current PEs as well as specific grade-band description of SEP CCCS and DCIs.

The third step in the process involves brainstorming various phenomena or real world problems that are related to the DCIs we unpacked. As we are doing so we are also brainstorming possible driving questions and sub-questions that work with the phenomena. The driving question guides instruction throughout the unit. This will anchor the phenomena in a relevant question for learners and sustain the reason for learning the science. Engaging phenomena and driving questions that require students to use elements of the DCIs, practices and crosscutting concepts are critical to developing engaging units.
Fourth, we develop a coherent sequence of learning tasks that integrate together various science and engineering practices with the core ideas and crosscutting concepts that will support students in figuring out. In so doing we ask: What do students need to be figure out first and what ideas will this help them develop? How would the ideas and practices develop over time? This sequence helps learners build sophisticated ideas from prior ideas, using evidence that builds from figuring out how various phenomena work. During this process we are always rethinking the phenomena or real world problems and driving questions. We often refer to this coherent sequence of learning tasks, learning goals and phenomena as a storyline. A storyline helps guide development of a project so that learners build sophisticated ideas from prior ideas, using evidence that results from figuring out phenomena and that builds toward meeting the PEs.
Fifth but integrated into step 4, we develop learning performances that are smaller in scope than performance expectations but use all three dimensions of scientific knowledge and link to figuring out learning tasks in the sequence. These learning performances also become part of the storyline or coherent sequence. Learning performances guide lesson development to promote student learning (Krajcik, et al. 2014; Krajcik, McNeill and Reiser, 2008). Learning performances are similar to performance expectations in that they integrate core ideas, practices, and crosscutting concepts, but at a smaller grain size. They support designers and teachers in designing lessons and assessments. Next, we develop what we will accept as evidence that learners have met the learning performance. Evidence is what we can observe students doing.

Each line of the storyline or coherent sequence specifies phenomenon students will experience and figure out, the scientific practices they will use, a learning performance to guide learning and the evidence we will accept if they meet the learning performance, and a figuring out statement (what part of the DCI are students figuring out).

Once we are comfortable with the storyline, we develop corresponding lesson plans. Each lesson builds from the storyline. Lesson plans provide directions for teachers for enacting the unit but they are not prescriptive. Lessons specify various instructional strategies that work well with PBL and resources that can be used in PBL as well as equity and fairness consideration.

We are constantly going through the storyline and lessons checking for coherence. We check the performance expectations, driving question, learning performance and evidence statements so that they align with each other. It is this alignment that builds coherence.

Our assessment design process: The shift towards a more coherent, engaging and three-dimensional curriculum has to be accompanied by a similar shift in the way students are being assessed in their learning. To address student assessment, in addition to developing the curricular units, three-dimensional assessment tasks that were aligned to NGSS performance expectations and not the curricular unit were also developed. These tasks were developed using a modification of a previously published process (Harris, et al., 2013). The process starts the same as the unit development process – identifying target PE's, unpacking them to create a common understanding of the key ideas embedded in them and brainstorming phenomena related to those ideas. From there, we proceed to create "integrated concept maps" which provide a visual representation of how the key ideas unpacked relate to one another. Using the concept map alongside the unpacking allows us to create task learning performances (TLP)- three dimensional statements (i.e. having the DCI, SEP and the CCC) similar to PEs and learning performances. These TLP describe what a student should be able do and form the basis for our task creation. Similar to the curriculum design process, TLP are also accompanied by evidence statements – what will be accepted as evidence for student mastery of the TLP as well as a focused knowledge, skill and ability statement (FKSA) that helps pinpoint the demand from the student. The next step is to consider the following: "what task design features will elicit the desired evidence? Determining those features will shape the creation of the task and associated rubric. This process, much like the curriculum design one, is highly principled, iterative and is accompanied by a fairness and equity framework to ensure that tasks are approachable by all students. Appendix 2 shows a part of the assessment task development to address the PE related to magnetic fields and energy stored in them. Also included in appendix 2 is the associated rubric for that task.

Measurement. Since optimal learning moments are defined on a fine grain time scale, our way of measuring student social and emotional constructs has to operate on a similar time scale. To gauge students' social and emotional constructs, students were given smartphones that had a special app that signaled them several times during instruction, prompting student to answer a short (90 sec) survey about what were they doing and how were they feeling. This measurement of in-the-moment engagement negates the averaged response one would get from a post-unit survey and allows us to pinpoint those moments during instruction and triangulate them with the curriculum.

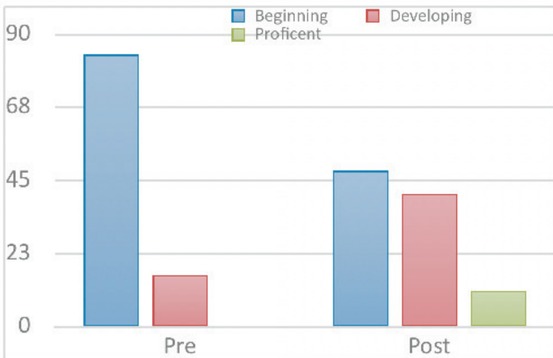
Participants:

For this manuscript, we present results obtained from a single class of 30 students from a high school residing in a large suburban area in a mid-west state of the US. The school is predominately African-American students (96%) with 24% of its students eligible for free or reduced lunch. This school has also scored below state average in science scores. The class science teacher participated in multiple days of professional development on the curricular units, project-based learning and three-dimensional learning as well as received constant support throughout the unit enactment via bi-weekly video conferences.

Results and Discussion

Student learning. Prior to the teacher enacting the curricular units, students were given the assessment task as a way to establish a baseline of student knowledge. After the unit was completed, students took the same assessment task. Both tasks were scored using the developed rubric in a manner where a score of 1 would be considered "beginning", a score of 2 would be considered "developing" and a score of 3 would be considered "proficient". The Percentage of students for each rubric score in the pre and post-unit test is shown below in figure 1.

Fig. 1: Students Pre and Post-test scores.



Most of the students (85%) scored "beginning" at the pre-test with a very low percentage (15%) scoring "developing" and none of the student scoring "proficient". This would indicate that students did not have prior knowledge about the subject students would explore and learn. After the unit, the percentage of students who scored "developing" rose to 40% and 10% of the students were assessed as proficient. A visual representation of student learning can be seen through the use of a modelling example. As a part of task, students were asked to draw the magnetic field lines between attracting and repelling magnets. A single student model (who scored 1 in the pre-test and 3 in the post-test) is shown below in figure 2.

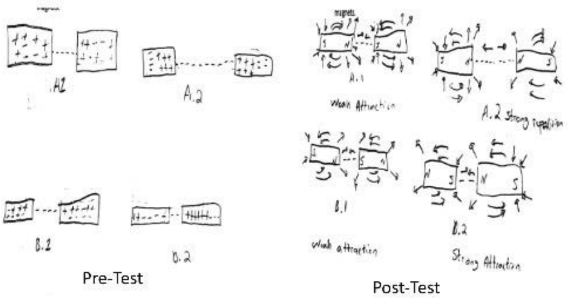


Fig. 2: Pre and Post-test modeling example

Looking at figure 2, it is evident that the student lacked the basic understanding of magnets through his depiction of the attraction between them as being an electrical phenomenon (as noted by the + and – signs in his model). Following the unit, the learner's disciplinary knowledge changed into a more complete understanding of the magnetic field line and the different shape between opposite and similar poles.

Social and emotional constructs. In-the-moment surveys, conducted during the unit enactment as well as during regular science instruction were used to collect data about students optimal learning moments, as well as other social and emotional constructs. Logistic regression was performed to determine if the students were more (odds ratio >1) or less (odds ratio <1) likely to experience these construct in the intervention curriculum as opposed to their regular instruction results are given in table 5.

Table 5: Social and emotional constructs

Construct	Odds Ratio	SE	Z	P value
OLM	2.1454	0.6844	2.39	0.017
Imagination	1.4399	0.3123	1.68	0.093
Solving Problems with Multiple Solutions	1.6861	0.3620	2.43	0.015

Looking at table 5, students were significantly more likely to experience optimal learning moments, sense of imagination and the feeling of being able to solve a problem with multiple solutions while engaging in project-based learning curriculum. Given the small sample size this finding is very impressive.

Conclusion and Implications

Three findings result from the study report in this paper:

Three major findings:

· Students improve in important social and emotional outcomes.

· Students show important learning outcomes related to knowledge-in-use.

The findings reported in the paper, while tentative, suggest that project-based learning has the potential to support students in developing both knowledge-in-use as well as important social and emotional learning. Curriculum materials and professional learning that focus on teachers implement the features of PBL can account for these outcomes.

Project-based learning engaging students in learning about natural phenomena and engineering challenges by having students investigate and design solutions. By so doing it increases learners understanding of how the world works.

Project-based learning engages students in doing science,

increase their conceptual knowledge of science, problem solving skills and innovation. A critical feature of PBL is that it increases students' wonderment and curiosity about the world. Because optimal learning is situational, the use of driving questions and phenomena that learners find of value can help to increase these movements.

One major implication emerges from this research:

• Potential of project based learning as a framework for promoting both social and emotional learning and knowledge-in-use.

PBL classrooms have the potential to become learning environments where teachers and all students engage in science to design and carry-out investigations to develop model and make and debate claims supported by evidence and reasoning. This is a dramatic shift in how science has been taught in the past. Our evidence shows that PBL environments foster imagination, problem solving, engagement, communication capabilities, working together, useable knowledge, and agency for all students. However, more systematic research is needed curriculum and assessment design.

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• Undergraduates – Ellie Paulson

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Models and Modeling in Science Education

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Abstract
After three years of preparation and development, Taiwan will formally launch its new science standards for grades 3-12 in 2018, to be implemented in 2019. This new framework identifies and describes the major objectives for science learning, which include core and crosscutting concepts, inquiry and practice, and the nature of science and scientific attitudes. To enhance students' systems thinking competence, for the first time, the standards include model construction as one of the competencies that students should develop in school. For chemistry, learning the history of the development of chemical models and experiencing modeling processes will be emphasized. In particular, the new standards will move the learning of chemistry from macroscopic to microscopic views of matter and reactions and shift from rote memorization to inquiry and practice. Also, for the first time, the particulate nature of matter will be introduced at the elementary level. The relevance of chemistry in one's daily life and the UN's sustainable development goals are also part of the new standards. In this article, I discuss the area of the new standards related to models and modeling practice in science learning and instruction in secondary education.

Introduction
The world is changing rapidly, and with this change is the risk of individual countries becoming marginalized. To safeguard against this, governments are focused on developing students' competence for the 21st century. In the area of science education and global literacy, there are several documents that delineate the competencies students should possess to be active, contributing members of society. For instance, the Organisation for Economic Co-operation and Development (OECD) Education 2030 states that students' knowledge, skills, attitudes, and values should help them to impact their surroundings; influence the future; understand others' intentions, actions, and feelings; and anticipate the short- and long-term consequences of what they do (OECD, 2018). However, the concept of competency implies more than just the acquisition of knowledge and skills; it involves the mobilisation of knowledge, skills, attitudes, and values to meet complex demands. The OECD Education 2030 also identifies three categories of competencies, the "transformative competencies," that together address the growing need for young people to be innovative, responsible, and aware, so they can create new knowledge and reconcile tensions and dilemmas. Similarly, the framework of the Programme for International Student Assessment (PISA) 2018 includes four dimensions in which students need to become proficient to be global citizens: examining local, global, and intercultural issues; understanding and appreciating the perspectives of others; taking action for collective well-being; and engaging in open and effective interactions with others.

The PISA aims to evaluate educational systems worldwide by testing the competence of 15-year-old students in reading, mathematics, and science. The number of participating countries/economies has increased over the past 18 years, from 32 in 2000 to 79 in 2018 when more than half a million students took the test. The PISA 2015 survey focused on science, with reading, mathematics, and collaborative problem-solving as secondary areas of assessment (OECD, 2015). The results revealed that Singapore outperformed all other participating countries/economies in science, followed by Japan, Estonia, Taiwan, and Finland, respectively. In fact, the Asian countries/economies (i.e., Singapore [1], Japan [2], Taiwan [3], Macau [6], Vietnam [8], Hong Kong [9], China [10], and Korea [11]) outperformed 72 other countries/economies. However, the results related to motivation for learning science revealed that some Asian countries (such as Japan, Korea, and Taiwan) scored below the OECD average. This was also evident for the enjoyment of science index (e.g., I am interested in learning about <broad science>), with Japan, Korea, and Taiwan again scoring below the OECD average. The percentage of students who expected to work in science-related professional or technical occupations when they were adults was alarmingly low for Asian countries/economies (such as China, Japan, Korea, Taiwan, and Thailand), compared to other countries whose students ranked lower on science skills and knowledge but higher on motivation and career expectations in science (such as Israel, Malaysia, and USA). Singapore was an exceptional case because it scored high on many aspects of the test. In terms of gender equality, the results revealed that Finland was the only country in which girls were more likely to be top performers than boys. Given these international results, we wondered how to promote students' scientific literacy as well as their motivation for, and interest in, learning science. The old adage, "give a person a fish and that person will eat for a day. Teach that person to fish, and you feed that person for a lifetime" was at the core of our desire to investigate how best to prepare students to use science effectively in the global world of the 21st century and simultaneously ignite their passion for the field.

The PISA 2015 results for Taiwan sparked discussion and debate among governmental agencies, researchers, educators, and the public. What had gone wrong in the educational system and what could be done moving forward so as to increase students' enjoyment and interest in the field of science? The PISA 2015 results likely had a direct, and certainly an indirect, impact on Taiwan's policymaking in education and present-day reforms in science education. Taiwan released its new curriculum guidelines (standards) for compulsory Grades 1-12 in November of 2018, with full implementation expected in 2019. The new framework identifies three pillars for science education (i.e., core concepts, inquiry competence in science, scientific attitude, and understanding nature of science) in order to cultivate students to become global citizens of the 21st century (see Figure 1). As for the core concepts, the guidelines break the learning objectives into five grade bands: Grades 1-2 for Level 1, Grades 3-4 for Level 2, Grades 5-6 for Level 3, Grades 7-9 for Level 4, and Grades 10-12 for Level 5). As for elementary school (Grades 1-6), the new framework calls for an integrated science approach for teaching science. For these grades, science teaching occurs three periods per week. No science was designated for Level 1. As for junior high school (Grades 7-9), science education includes biology, earth science, and physical science, with the integrated approach to instruction being less of a focus during these grades. These grades also receive three teaching periods per week for science. As for high school (Grades 10-12), eight credits in separate subjects (e.g., chemistry, biology, earth science, and physics) plus 4 credits in inquiry and practice are now required of all students in Grades 10 and 11. Available courses now include 8 credits in biology, 10 credits in chemistry, 4 credits in earth science, and 10 credits in physics for selected science courses for science-major students. These courses will be provided for students at grades 11-12. The curriculum guidelines were aligned with international trends (e.g., Next Generation Science Standards [NGSS]) that emphasize core ideas, crosscutting concepts, and practice in science (National Research Council, 2013). The biggest changes in the new standards are the inclusion of 4 credits at the high school level in inquiry and practice for learning science and thinking skills for reasoning and constructing scientific models. This is the first time the use of modeling in science learning and practice has been the focus of education standards. In this paper, I review the work in the area of modeling competence and discuss how the modeling-based approach can be used for science education.

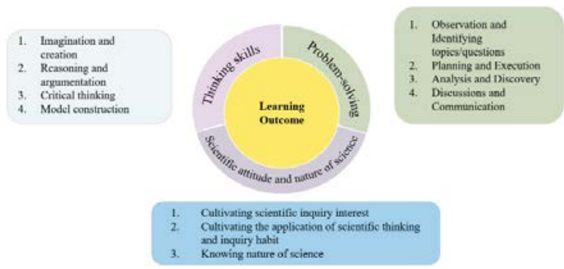

Fig. 1: The learning outcome of the science curriculum for grades 1-12 in Taiwan (MOE, 2018)

The Emerging Call for Scientific Modeling Competence

Scientific modeling has attracted a lot of attention in science education over the past two decades. A Framework for K-12 Science Education: Practices, crosscutting concepts, and core ideas

(National Research Council, 2012) recognizes the importance of developing students' modeling competence via developing and using models in the science classroom. The NGSS (2013) also advocate for the integration of modeling activities into school science practice to allow students to experience the processes that scientists employ as they investigate and build models and theories about the world (p. 30). Given our increased understanding about the function of modeling in science, science curricula need to stress the role of models explicitly and provide students with modeling tools so that they come to value this core practice and develop a level of facility in constructing and applying appropriate models (National Research Council, 2013, p. 59). This emphasis on modeling is new and will need to be an explicit element of teacher preparation.

Scientists use models to explain and predict how scientific phenomena function. With this competence in practice, scientists are able to link their hypotheses, data, experiments, and interpretations with scientific models. The processes of developing and using models also play important roles in understanding scientific theories in science learning.

To successfully implement modeling activities in science classrooms, students' understanding of the nature of models and modeling processes needs to be carefully considered and enhanced. Research points out that engagement in modeling and in critical and evidence-based argumentation invites and encourages students to reflect on the status of their own knowledge, their understanding of how science works, and their personal competence in problem-solving. As they involve themselves in the practices of science and come to appreciate its basic nature, their level of sophistication in understanding how any given practice contributes to the scientific enterprise continues to develop across all grade levels (National Research Council, 2013).

Several influential organizations have been proactive in highlighting the value of models and emphasizing the important role models should play in science teaching and learning. Too often school curricula fail to focus on the development of scientific models, and textbooks also fail to make appropriate use of historical and epistemological models. As a result, it is not surprising that teaching commonly relies on hybrid models that mix scientific and alternative models (e.g., Gobert & Pallant, 2004).

Uses of the Modeling-Based Approach

Models are constructed through modeling, a process of developing concrete representations of abstract ideas in science (e.g., heat) and the underlying mechanism(s) that causes the physical phenomenon and is driven by observations of that phenomenon. Models and modeling are considered integral parts of scientific literacy, reflecting educators' wider efforts to introduce and engage students in authentic scientific inquiry (e.g., Gilbert & Justi, 2016). Several modeling processes have been identified by researchers, with the general steps involving the following: making systematic observations and/or collecting experiences about the phenomenon under study; constructing a model of the phenomenon based on those observations and experiences; evaluating the model against standards of usefulness, predictive power, or explanatory adequacy and commenting on their appropriateness; using models to describe, predict, or explain phenomena; and reflecting and revising the model and applying it in new situations (e.g., Lehrer and Schauble 2006; Louca & Schwarz et al., 2009; Louca, & Zacharia, 2012). Among this research, Halloun (2006) identified five steps of modeling, including model selection, model construction, model verification, model analysis, and model deployment. These steps explicitly state how to gradually develop modeling practices and highlight the stages necessary to construct scientific models. Over the past 10 years, my research group has been investigating students' use of models and the use of modeling-based instruction in high school science classrooms. The specific science topics our research has addressed involve atomic structure, electrochemistry, gas laws, and heat and temperature. Based on the above research on the development of models in field of science and the findings from my research on science education, I developed a modeling framework for promoting students' modeling competence that includes four stages: model development, model elaboration, model transfer, and model reconstruction (Chiu, 2008, 2016a, 2016b). Each stage is broken into two steps (see Figure 2). The eight total steps are model selection (MS), model construction (MC), model validity (MV), model analysis (MA), model application (MApp), model deployment (MD), model revision (MR), and model transformation (MT). On top of this framework, we superimpose driving questions as a starting point for a modeling activity (no questions, no inquiry, no modeling). In the following sections, I detail my work on modeling and chemistry learning involving students in Grades 8-12.

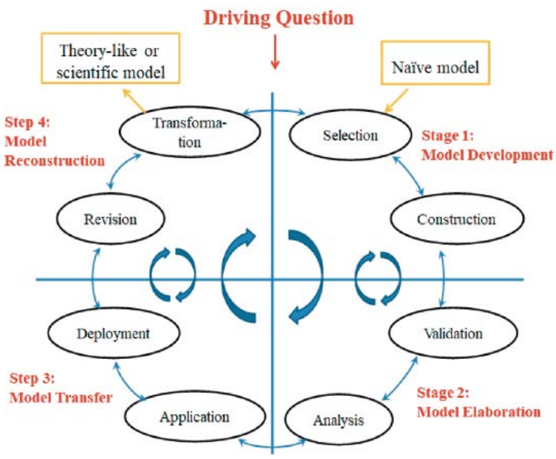

Fig. 2: The framework of modeling processes

Case 1: Modeling-based textbook analysis

Based upon an earlier version of my modeling processes framework, my research team analyzed 16 high school chemistry textbooks to examine the presence and status of modeling in each text (Liu & Chiu, 2010). The 16 textbooks were chosen from local publishers in Taiwan and were designed for science instruction with Grade 10 students. Table 1 shows that the majority of the textbooks (82.8%) emphasized model construction, followed by model description and selection (72.7%). Also, slightly more than 50% of the textbooks' references to models involved model validation or deployment. Model application was mentioned the least. From the analyses presented here, we found little emphasis on Stages 2 and 3 that have the potential to promote higher-order modeling competence.

Table 1. The frequencies of steps of modeling processes included in the 16 textbooks

	TS01	TS02	TS03	TS04	TS05	TS06	TS07	TS08	TS09	TS10	TS11	TS12	TS13	TS14	TS15	TS16	Total (128)
S	7	7	8	5	7	6	5	5	6	4	5	6	4	6	6	6	**93 (72.7%)**
C	8	7	8	7	8	5	4	7	8	3	8	8	6	7	6	6	**106 (82.8%)**
V	2	4	2	3	5	3	4	6	4	2	6	6	6	5	4	4	**66 (51.6%)**
A	2	3	2	3	3	2	2	5	4	1	3	6	3	3	4	2	**48 (37.5%)**
D	2	5	4	5	6	5	3	7	6	2	7	6	5	4	5	3	**75 (58.6%)**
	21	26	24	23	29	21	18	30	28	12	29	32	24	25	25	21	

Note: Codes for the modeling processes: model descriptions and selection (S), model construction (C), model validation (V), model analysis and evaluation (A), and model deployment (D).

Research has indicated that not only do students lack understanding of the nature of models and modeling processes, but science teachers also lack understanding of the functions of models and how to construct models for teaching and learning in science (Van Driel & Verloop, 2003). Given that science textbooks generally do not emphasize the value and function of models or discuss how scientific models were constructed, it is no surprise that students and teachers both need to improve their modeling knowledge and skills.

Case 2: Modeling-based Text to Improve Students' Modeling Competence

One of the main goals of chemistry teaching is to facilitate students' understanding of the submicroscopic representations used to explain natural phenomena. We took this into consideration when we designed modeling-based texts on the ideal gas law (Jong, Chiu, & Chung, 2015). We then investigated the effects of these modeling-based texts on tenth graders' modeling competencies. We used the latest version of our modeling framework (Chiu, 2016b), which included explicit descriptions and representations of modeling processes (i.e., model development, elaboration, transfer, and reconstruction) and submicroscopic perspectives of gas particles. Prior to the experimental phase, 15 students participated in two 20-minute training sessions over a 1-week period to learn how to read the required text and used a recorder to record their answers to science questions. The results revealed that the students not only developed their modeling competencies but also constructed scientific mental models of the ideal gas law after reading the modeling-based texts. On the basis of their mental models, students interpreted macroscopic phenomena with submicroscopic concepts of gas particles for some modeling stages. This study demonstrates that modeling-based text enables students to better apply scientific information in the construction of their conceptual knowledge and helps them develop their modeling competencies compared to the non-modeling-based text group. A midtest, including an interview and a formative assessment, was arranged during Week 4. A posttest, including an interview and a multiple-choice test, was conducted after the reading of all texts during Week 7. Then, a delayed posttest was administered 3 weeks later. The findings from this study are encouraging and suggest that teachers and students can both benefit from even minimal use of modeling-based text.

Case 3: Modeling-based Inquiry Instruction

There is considerable research in the area of modeling-based instruction (i.e., Schwarz et al., 2009) that led to significant advances in the field. Researchers point out that students should be taught to think like scientists who construct their hypothetical models and collect data to prove them to be acceptable. As part of this instruction, modeling processes need to be integrated into authentic learning contexts in the science classroom. Based upon the research and our own professional experiences, we developed our 4Ming-stage framework for designing learning materials to cultivate students' modeling competence.

In our study (Chiu, Zeng, & Chung, 2018), we examined two groups of eighth grade students in a municipal junior high school in Taipei, Taiwan: One group received modeling-based text and confirmation inquiry instruction and the other received conventional instruction. All of the students completed a pretest, pre-interview, posttest, and post-interview. The students received different versions of text on the topic of electrochemistry. We found that there was a significant difference in the posttest for the modeling-based instruction group but not the conventional instruction group. As for comparisons between the two groups, the students who received modeling-based instruction outperformed the students who received conventional instruction on all measures, including model validation and model deployment, which are considered to be extremely challenging for students. Also, according to the results, we found that the modeling-based text and inquiry activities not only improved students' content knowledge about electrochemistry but also facilitated students' modeling competence. The differences in cognitive performance and modeling competence between the two groups were statistically significant. We found that the modeling-based inquiry instruction about modeling processes allowed the students to understand the concepts in a more systematic way. This authentic learning environment provided opportunities for students to elaborate on their ideas about scientific phenomena and test their hypotheses with various designs in order to verify and apply them in different situations (e.g., Krajcik et al., 1998; Schwarz et al., 2009). Researchers have argued that implicit and explicit guidance leads students to different cognitive performance. In our study, explicit instruction on modeling-based inquiry allowed students to focus their attention and effort on authentic tasks, so they could generate quality models of electrochemistry. Modeling-based inquiry has the potential to uncover the complexity of science concepts via a systematic approach to instruction that facilitates student comprehension.

The above study revealed that the students in the modeling-based inquiry group outperformed the conventional instruction group not only in terms of overall performance but also in terms of higher order systems thinking. More importantly, the students in the modeling-based instruction group outperformed the conventional instruction group on overall modeling competence and model construction and validation sub-modeling competence. The modeling assessment tool we developed for this line of research was able to identify students' level of competence in modeling practice. We believe this tool has the potential to be implemented at the school level to inform science teaching and learning.

Case 4: Extending modeling-based inquiry for outdoor activities

SageModeler is educational software created by Concord Consortium in Massachusetts. Research indicated that creating an authentic learning environment can help students develop their modeling and practice competence (Damelin, Krajcik, McIntyre, & Bielik, 2017). We attended a workshop conducted by Krajcik and Novak (Krajcik & Novak, 2017) and then adapted the software based on the modeling processes and used it as a learning tool in a water quality activity at a local secondary school (Grades 7-12) in Taipei city, Taiwan. We first held a day and a half workshop on familiarizing participants with the software. Then, a 2-day workshop was carried out. The activity was to test the quality of water over 6 weeks (315 hours). All the 27 9^{th} grade students were required to work in groups. They had to find the relevant questions and relationships among the variables (see Figure 3). Once this was completed, the students were required to collect data from the field. Although SageModeler did not allow for systemic assessment of the students' constructed models, we did see increasing complexity with more variables involved in their consideration after students collecting their data. A set of data from the weather broadcast bureau was provided for the students to test their models. We believe this software has the potential to engage students in constructing, verifying, and applying their models in authentic project-based activities.

Krajcik and Novak's workshop

An authentic modeling-based activity via the use of SageModeler

Fig. 3: A modeling-based field trip on water quality

Concluding remarks: The need for modeling-based assessment

In the cases discussed here, there were several efficient ways to introduce modeling into science instruction and to evaluate the effectiveness of this instruction on students' modeling competence. Modeling-based instruction was found to facilitate students' mental models of several topics involving transformations among macro, micro, and submicroscopic representations. The studies revealed that the students in the modeling group outperformed the comparison group not only in terms of the overall performance but also on the higher order thinking of system of the scientific models. Give a man a fish and you feed him for a day or teach him how to fish and you feed him for a lifetime? We conceptualized modeling competence and motivation for science as evolving from opportunities to develop problem-solving skills.

However, there are limited studies on effective modeling-oriented assessment tools that evaluate students' modeling competence (Namdar & Shen, 2015; Nicolaou & Constantinou, 2014). As such, the modeling assessment tool of identifying students' levels of competence in modeling practice should be an emphasis in future. This direction of the task could be extended to evaluate teachers' modeling competence as well.

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Pedagogical Content Knowledge and Assessment Knowledge in Teaching the Energy Topic

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Abstract

Our research focused on the teaching and assessing the Energy and Dynamics in Chemistry unit in 12th grade. The research question was: What are the characteristics of the Pedagogical Content Knowledge (PCK) and the teachers' Assessment Knowledge (AK) while teaching the energy unit? The research method combines quantitative tool – questionnaires with open- and closed-ended questions; and qualitative tools – assessment tasks that teachers' developed for the characterization of their PCK and AK. The research participants were 63 chemistry teachers who prepare students for matriculation exams in chemistry and teach the energy unit as well as participated in summer workshops at the Technion.

The analysis of the findings showed that teachers' assessment knowledge (AK) received a lower score than PCK received in the questionnaire. In analyzing assessment tasks, we found that most teachers combined higher order thinking questions at different levels of understanding in teaching chemistry. There were different assessment characteristics—some of which were traditional and some innovative, when applying the alternative assessment within the energy unit.

The research contributes to better understanding of chemistry teachers' pedagogical content knowledge and assessment knowledge that chemistry teachers poses as they teach energy tasks; and designing indicators for alternative assessment tasks developed by teachers.

Introduction

About two decades ago the chemistry curriculum has been changed. The traditional instruction style, which was characterized by memorization of process and concepts, and high cognitive load, was replaced with new curriculum which emphasized a transition to a learning process that encourages and promotes higher order thinking skills and the relevance of chemistry to the students' lives (Avargil, Herscovitz, & Dori, 2012; Barnea, Dori, & Hofstein, 2010). As part of these changes, *Energy and Dynamics in Chemistry* unit was developed by the Chemical Education Group at the Technion, Israel Institute of Technology for 11th or 12th grade chemistry students. This unit focuses on concepts and processes about the subject – kinetics, chemical equilibrium, energy in chemical processes and thermodynamics.

Today, the new reform promotes change in the teaching, learning and evaluation methods, and some of the unit's contents have been transferred to an alternative teaching and assessment approach while incorporating higher order thinking and scientific skills for practices of everyday phenomena (Lavi, Shwartz, & Dori, 2019).

Every summer, the Faculty of Education in Science and Technology conducts several training workshops on alternative assessment methods in chemistry, which include teachers experiencing the development and assessment of learning tasks. These tasks constitute a formative assessment and involve questions at levels of thinking beyond what is required from the student in traditional learning as part of a summative assessment (Dori, 2003).

There are several studies in which researchers investigate characteristics of teachers' knowledge types: Content knowledge (CK), pedagogical knowledge (PK), pedagogical content knowledge (PCK), and the teachers' assessment knowledge (AK) while teaching science in general (Abel. 2017; Akın, & Uzuntiryaki-Kondakci, 2018; Shulman, L. 1986) and chemistry in particular (Avargil, Herscovitz, & Dori, 2013).

Research Question and Method

In this study, the research question was based on the teachers' self-reports and self-designed tasks: What are the characteristics of the Pedagogical Content Knowledge (PCK) and the teachers' Assessment Knowledge (AK) while teaching the energy unit?

The data collection was carried out using mixed-methods including: (1) quantitative tool - questionnaire with open- and closed-ended questions; and (2) the development of assessment tasks for the characterization of teachers' PCK and AK. These tasks expressed their teaching and evaluation methods in their own classrooms while they teach the energy unit and evaluate their students' performances.

The research participants were 63 chemistry teachers who prepared their students for matriculation exams in chemistry and teach the energy unit as well as participated in the summer workshops at the Technion.

Findings

In the open-ended part of the questionnaire, teachers responded to the question about their perceptions with respect to the knowledge that is needed to understand the energy unit. We analyzed 79 statements that were written by 58 participants. Some of them mentioned more than one type of knowledge. According to the teachers' perceptions in this open-ended part in the questionnaire, we found that 34% of the statements focused on PCK, 32% on CK, 19% PK, and only 15% mentioned that they need AK for teaching and understanding the energy unit. This analysis of the findings showed that teachers' AK received a lower score than PCK. We found similar results in the closed-ended part of the questionnaire. In the closed-ended part of the questionnaire, the average score of the statements according to the types of knowledge in the energy unit were as follows: CK – 4.52, PCK – 4.19, PK – 3.94, while AK received only 3.25 (on Likert scale of 1-5).

In analyzing assessment tasks developed by these teachers, it was found that most of the teachers combined higher order thinking questions at different levels of understanding in teaching chemistry. For example, one teacher developed an assignment on equilibrium reactions using KAHOOT application with focus on Ammonia production. The assignment involved higher order thinking skills such as question posing and graphing skills and encouraged the use of three chemistry understanding levels – macro, micro, and process.

We also found that among the teachers there were different assessment characteristics when applying the alternative assessment within the 30% of the energy unit, some of which are traditional and some innovative. The teachers who implement an alternative assessment approach noted that this learning enables better integration of the material learned with everyday life and enables a deeper understanding of the topic being studied. However, they claimed that an alternative assessment takes a lot of time to prepare and test students' work, and it is difficult to assess each student's performance separately. In addition, the tasks that require high levels of thinking, such as posing questions, take a lot of their time while teaching the students for mastery learning until they performed correctly. Therefore, the teachers do not use alternative evaluation methods frequently.

The analysis of the questionnaire responses for understanding the teachers' perceptions of the curriculum in the Energy Unit revealed that: (1) most of the teachers think that it is the combination of high levels of thinking in the unit that distinguishes it from the other chemistry units; (2) most of them were satisfied with the change in the curriculum according to the new program and think that this is a relief for students; (3) most of the teachers relate to the change in the curriculum and teach according to the new division 30/70 of the program, although some teachers teach all the topics according to the former program; (4) teachers' perceptions of the learning unit showed that most teachers believe that the scientific concepts presented in the unit by multiple representations – visual, textual, along with the four understanding levels in chemistry, distinguishes it from other learning units; finally, (5) most teachers believe that an alternative assessment should be incorporated into the energy unit but very few teachers do so.

Discussion and Contribution

The challenges and insights of the chemistry teachers who teach the 30% content in the energy unit which were found, can contribute to the planning of future professional development courses for chemistry teachers who experience and face similar processes while teaching and evaluating their students using this unit. A broader integration of the tasks developed by teachers for such training may provide insights into the implementation of alternative assessment tasks in the chemistry classrooms not only in the energy topic; and may even be used for future training of chemistry teachers.

In the theoretically aspect, the research contributes to the establishment of new knowledge with regards to chemistry teachers' perceptions of teaching and assessing the energy unit; and to the development of pedagogical content knowledge and assessment knowledge the chemistry teachers poses as they teach energy tasks.

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