Part 5 / Strand 5

Teaching-Learning Sequences as Innovations for Science Teaching and Learning

Editors: *Italo Testa & Nikos Papadouris*

Part 5. Teaching-Learning Sequences as Innovations for Science Teaching and Learning

Design of teaching and learning materials. Classroom implementation, refinement and evaluation of teaching sequences. Exchange and adaptation of teaching-learning sequences. Adoption and transformation of teaching materials. Factors that influence teacher ownership.

Part 5: Teaching Learning Sequences and Innovative Interventions for Teaching and Learning Science

Editors: *Italo Testa & Nikos Papadouris*

Introduction

This chapter gathers the contributions to the ESERA 2021 e-proceedings for STRAND 05. The strand focuses on Teaching Learning Sequences (TLSs), namely structured sequences of instructional activities, with well-documented suggestions for teachers and expected student learning gains. In other words, studies in this strand are prominently empirical, including small-group interventions, with emphasis on the evaluation of students' learning and affective outcomes.

ESERA Conference 2021 was held remotely due to the COVID-19 pandemic. Despite such a modality, overall, 19 oral contributions, one symposium and 7 posters were presented in this strand. Eight oral contributions and 4 posters have been included in the e-proceedings.

Amongst the eight studies presented as oral contributions, two concern physics topics, two reports on biology topics, two address teachers' adaptations of TLSs, whereas the last two concern the development of students' modelling skills.

The two contributions in the physics domain address atomic structure and heat and temperature. Kardaras and Kallery present a TLS about the Bohr Atom and spectroscopy using the Model of Educational Reconstruction as a theoretical framework. The TLS also exploits Tracker software to analyze Sun's spectrum. Results show a significant positive impact on students' learning outcomes. Monti and Daffara describe a TLS that focuses on heat and temperature. The TLS uses online sensors and thermal cameras to study temperature *vs* time graphs and heating processes. The TLS was implemented with prospective primary teachers. Results show that the prospective teachers found helpful the use of sensors and thermal cameras to introduce the targeted topics.

One of the two contributions about biology topics address biodiversity. Alitto et al., in particular, present a TLS to improve Brazilian students' knowledge of marine biodiversity. The second contribution concerns genetics. Specifically, López-Fernández and Franco-Mariscal used the Simpsons characters to address genetics topics in a TLS implemented with prospective teachers. Results suggest that the proposed TLS could facilitate the teaching of science topics, although adaptations were deemed important for classroom implementation.

The latter issue, namely the teachers' adaptations of TLSs when incorporating them into their classroom practice, is addressed by two contributions. Gieske and Bolte present the adaptation of a chemistry-based TLS in different phases (disaggregated instruction approach) to meet the conditions of a diverse student population in a multilingual, urban setting in Germany. Despite a promising, positive effect, the results of the main study do not show significant differences between the treatment and control groups. The second study by Michailidi and Stavrou specifically concentrated on teachers' adaptations of TLSs and focused on innovative topics such as nanotechnology, microplastics and milk carbohydrate. The results show that teachers carried out adaptations along three dimensions of the TLS: the activity sequence per se (adding or skipping an activity), the kind of teaching materials used, and the targeted science concepts.

The two contributions to modelling present different methods and contents. Muñoz-Campos et al. present a TLS about models of milk fermentation. The results show that students' models evolved towards a scientific view during the implementation of the TLS. Taramopoulos and Psillos explored the development of procedural knowledge and experimentation skills in high-school students after an inquiry-based TLS about AC electric circuits. The results show that the TLS was effective in helping students advance both their design and experimentation skills.

The four remaining papers concern the poster sessions of the conference. In the Carvalho and Guerra paper, a 4-hour TLS about the effects of microorganisms on human health is presented. The paper also reports the TLS development and validation by two external experts. Angele et al. developed an interdisciplinary TLS about foodstuffs and alcoholic long drinks. The authors present the design principles, example materials and how they drew on the empirical data to redesign the initial version of the TLS. The third paper, by Becker and Hopf, describes the development of a TLS about energy – field approach. The authors present the activity sequence and two cycles of design and evaluation, including examples of how the initial TLS was revised. Finally, Sutrini et al. discuss a TLS about quantum computation and information. Using the Model of Educational Reconstruction, the authors describe the activity sequence and preliminary results concerning students' engagement in the activities and conceptual understanding of the targeted concepts.

Overall, the studies presented in this chapter of the e-proceedings expand the current TLS field, drawing on a range of theoretical and methodological frameworks. All papers provide useful insights into the research field of TLS development with implications that could be relevant to a broad range of contexts.

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TEACHING THE MODEL OF THE BOHR ATOM USING THE LINE SPECTRUM

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Line spectra generated by electron transitions between energy levels of the atoms are important for the understanding of contemporary physics. Teaching them with experimental activities can motivate students to learn and help them obtain a more profound and qualitative understanding of the atomic structure and its applications. In this study, we present a module for teaching the model of the Bohr atom using linear spectra of chemical elements. The design of the module was based on the model of educational reconstruction. Students' previous ideas were investigated, and textbook analysis was carried out. The students in upper secondary education were engaged in a combination of computer simulations and hands-on activities that helped them develop a more complex and structured knowledge of the subject. A ten-multiple choice questionnaire was administered before and after the implementation. The data was analyzed both qualitatively and quantitatively. The results showed that the intervention had a significant positive impact on the students' learning outcomes.

Keywords: Conceptual Understanding, Inquiry-based teaching, Models in science

INTRODUCTION

The understanding of linear spectra plays a key role in the study of atomic structure. Although teaching linear spectra is a fundamental part of teaching Physics in many schools, research on students' learning and teaching is lacking in this content area (Ivanjek et al., 2020; Savall-Alemany et al., 2016). This, especially in the Greek curriculum (since the study has been carried out in Greece), places a greater emphasis on mathematical formalism than on the knowledge of the phenomenon and leads students to memorize mathematical equations without fully understanding them. Added to the above is the fact that the textbook used in the 2nd grade of Lyceum follows a similar structure as university textbooks without modifying or adapting the topic to the student's cognitive level or pre-existing knowledge, thus adding further difficulties in comprehension. In view of all the above, our aim was to assist students in secondary education to acquire an integrated view of the model of the Bohr atom and line spectra of the atoms. In the present study, we investigate how the experimental activities used in an intervention with the above aims impact on students' learning of the model of the Bohr atom.

Theoretical background

In the 19th century, scientists discovered that each element produced its own discrete set of spectral lines. They used the spectroscope to observe these atomic spectral lines. After examining the atomic spectra of various chemical elements, they noticed that hydrogen could emit and absorb only four wavelengths in the visible spectrum.

In 1885, Balmer noted a regularity in the frequencies of the Hydrogen spectral lines, and to calculate the wavelengths of the spectral lines that specific energy transitions produce, he proposed the following formula:

$$\frac{1}{\lambda} = R\left(\frac{1}{n_x^2} - \frac{1}{n_i^2}\right)$$

where n_x and n_i are integers and R is Rydberg constant with a value of $1.0973732 \cdot 10^7 m^{-1}$.

Rydberg also noticed that the sum of the frequencies of two lines in the spectrum of hydrogen often equals the frequency of a third line (Hewitt, 2014). Although Balmer and Rydberg could not explain the cause of this phenomenon, this regularity had an enormous impact on the description of the atomic structure. It was Bohr who formulated a theory to explain the spectral lines.

In 1913, Bohr applied the quantum theory of Planck and Einstein to the nuclear atom of Rutherford and formulated its model. The basic ideas of the Bohr theory, as it applies to an atom of hydrogen, are as follows: Electron moves in circular orbits with varying radii around the proton under the influence of Coulomb's attractive force and occupy "stationary" states (of fixed energy) at various distances from the nucleus. These orbits are stable and are the ones in which the electron does not radiate. He also supported the idea that radiation is emitted by the atom when a quantum jump occurs from a higher to a lower energy state. Thus, the equation that can be used to calculate the energy and frequency of the emitted radiation is

$$\Delta E = E_i - E_f = h \cdot f$$

Where E_i is the energy of the initial state, E_f is the energy of the final state.

Bohr proposed that the emitted photon's frequency is not the classic frequency at which an electron is vibrating but, instead, is determined by the energy differences in the atom. From there, Bohr could take the next step and determine the energies of the individual orbits (Hewitt, 2014).

To describe the model of the Bohr atom, several concepts and phenomena such as circular motion, Coulomb's law, kinetic and potential energy, energy conservation, emission and absorption of light, and discrete energy levels are required. The synthesis of these concepts and phenomena assists students to gain a deeper understanding of them (Arons, 1990).

Bohr's hydrogen model was extended to other elements in which all but one electron had been removed. These atoms are called hydrogen-like atoms. If the atomic number is Z, then the nuclear charge is Ze and such one-electron atoms are singly ionized He^+ or doubly ionized lithium Li^{2+}. Then, since the energy levels of the Bohr atom are $E_n = E_1/n^2$, the energy levels of these atoms are multiplied by Z^2. Also, atoms of the alkali metals are approximately hydrogen-like.

Ionized elements such as He^+, Li^{2+} and Be^{3+}, were suspected to exist in hot stellar atmospheres where frequent atomic collisions occurred with enough energy to completely remove one or more atomic electrons. Bohr showed that several mysterious lines observed in the Sun and stars could not be due to hydrogen but were correctly predicted by his theory if attributed to singly ionized helium (Serway et al., 2004).

METHODOLOGY

Design and implementation of the module

The teaching intervention was designed taking into consideration the physics curriculum of the country (Greece) and, in particular, the concepts of physics that it includes, as well as the duration of the course. The design of the module was based on the model of educational reconstruction (Duit et al., 2012): it is iterative, with three intertwining components: (i) analysis of the content structure, (ii) empirical investigation (textbook analysis and student ideas), and (iii) construction of instruction.

In order to help students, deepen their knowledge and acquire a functional understanding of the atomic structure according to the model of the Bohr atom, we developed experimental activities for a direct and articulate experience of the line spectra. The main learning objectives of these activities are for students to understand the description of the model of the Bohr atom, to observe and measure the wavelengths of the spectral lines and determine the relationship between these wavelengths and the atomic energy levels, to be able to relate theory to starlight spectra, and to process the Sun's spectrum and observe the lines of absorption. On the one hand, Starlight can help students acquire a more profound knowledge of the topic and, on the other hand, strongly motivate their learning of the subject.

The present study was guided by the following research questions:

(1) How can we design a teaching module based on a sequence of activities that helps students understand Bohr's atomic model within the frame of linear spectra?

(2) What is the effectiveness of the designed teaching module in students' conceptual understanding of the topic related to the linear spectrum of the atoms, especially of the Hydrogen atom?

The first steps towards an educational reconstruction of Bohr's atomic model and its linear spectrum consisted of identifying key concepts and laws and reviewing students' conceptions of this topic**.**

Our intervention lasted 4 hours and was implemented to 38 students aged 17. The final implementation was preceded by a one-year pilot implementation. The instructional approach used was that of structured inquiry. The students were engaged in a combination of computer simulations and hands-on activities. They recorded and processed their observations.

In the first activity, students were introduced to Bohr's model of the atom by using software (available at https://astro.unl.edu/naap/hydrogen/hydrogen.html) and investigating the interaction of a Hydrogen atom with photons of various wavelengths. With the use of the software, the students predicted and confirmed the assumptions of the model.

In the second activity, students observed the linear spectra of several gas discharge tubes (Hydrogen, Helium, Mercury, and Neon) and measured the wavelengths of the lines that appeared in the spectrum, focusing on the Hydrogen spectra (Figure 1). Then, by applying the mathematical equations of the Bohr model, they calculated the energy of the atomic levels of Hydrogen and found the electron transitions which produce the lines of the spectrum. Having established the description of the Bohr atom, we sparked students' interest and fostered useful discussion by posing the following question: How can we calculate the Planck constant using a spectroscope and a lamp containing a heated gas of Hydrogen? The purpose of this experiment was to assist students to work using the scientific method and observe the spectrum, measure the wavelengths of the lines, calculate the energy levels, and finally calculate the Planck constant.

Figure 1. The light emitted from a lamp containing a heated gas of H_2 and its line spectrum.

In the third activity, we initially started discussion by posing the following question: how can we determine the wavelengths of the dark lines in the Sun's spectrum knowing that the Sun, among other elements, also consists of Hydrogen? Firstly, we described the formation of the stellar absorption spectra, and subsequently, students used the spectroscope to analyze the sunlight and observe the resulting spectrum (Kardaras & Kallery, 2020). Also, a camera, which was adjusted to the spectroscope's eyepiece, took a photo of the solar spectrum. We asked students to calculate the wavelengths of the dark lines of the solar spectrum due to Hydrogen in order to apply their theoretical knowledge in practice, providing them with experience from authentic situations (Figure 2).

Figure 2. The spectrum of the Sun, taken with a spectroscope, shows the expected dark lines drawn by the students and considered to be the result of the existence of hydrogen.

Students then processed the photo of the Solar Spectrum they took and specifically analyzed it with the Tracker software (see Figure 3), (available at https://physlets.org/tracker/), which is an Open-Source Physics tool built on the OSP code library (Brown, 2020). After that, they extracted the experimental data obtained from the spectrum, processing the wavelengths of the spectral lines, and confirmed that the Sun consists of Hydrogen, Sodium, and Iron (Figure 3). In particular, for the Hydrogen atom, students determined the corresponding electron transitions that produced its lines.

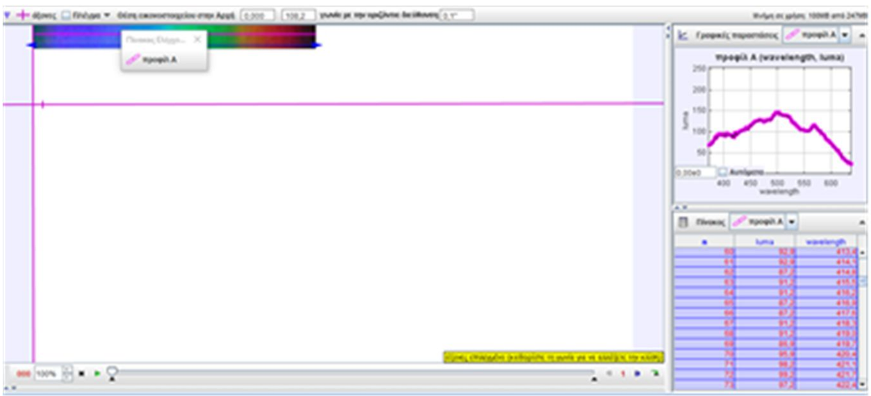

Figure 3. Screenshot of the Tracker analysis of the Sun's spectrum having defined the range of the wavelength. Many lines are observed as absorption peaks (H_a, H_β, Na, Fe).

In the fourth activity, students were shown images of the stars' spectra and were asked to find out what chemical elements the stars are made of. Also, students compared the positions of the spectral lines of the Solar spectrum with those of the chemical elements and matched the lines that appeared at the same wavelengths (Figure 4).

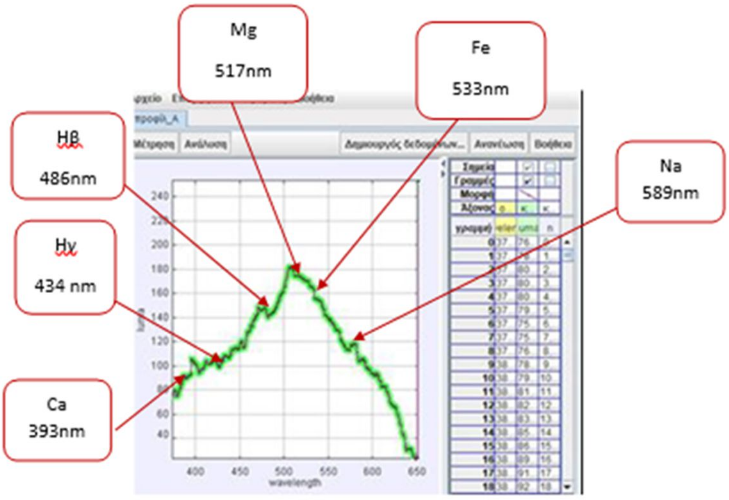

Figure 4. Identifying chemical elements in the Solar spectrum.

Assessment of students' learning outcomes

To evaluate students' learning progress, in addition to the other evaluation tools (worksheets and interviews), we used a questionnaire of ten multiple-choice items, two of which are presented in Table 1.

Table 1. Sample questions for the evaluation of students' learning outcomes.

Q1. Excited hydrogen atoms are at energy level n. If there are six lines in the linear emission spectrum, then n is a. n=3 b. n=6 c. n=5 d. n=4
Q2. An excited hydrogen atom is in energy level n=3. Which is the least energy for the excited atom to be ionized? a. 13.6 eV b. 1.51 eV c. 12.09 eV E_4 = -0.85eV ———— n=4 E_3 = -1.51eV ———— n=3 E_2 = -3.4eV ———— n=2 E_1 = -13.6eV ———— n=1
Q3. An atom with three energy levels (the ground and two others) absorbs photons of white light and its electrons make the transition to the two other levels. During its deexcitation, it emits photons: Which of the following spectra will we notice? a. An absorption spectrum with a single dark line. b. An emission spectrum with two dark lines. c. An emission spectrum with three colored lines. d. An emission spectrum with two colored lines.

Students were also asked to complete a questionnaire with open-ended questions (see Young et al., 2014; Hewitt, 2014) to test their understanding of the topic and to examine whether they had developed critical and scientific thinking about this subject area. They were asked to justify their responses in writing by explaining their reasoning in words and mathematical calculation. The levels of understanding of each response were evaluated as correct, partially correct, or incorrect. Two of the questions are presented in Table 2.

Table 2. Sample open-ended, explanation-type questions for evaluating the quality of students' argumentative discourse.

Open-ended questions
Q1. Could you explain why the Hydrogen spectrum has many lines although the Hydrogen atom consists of only one electron?
Q2. In the Sun's spectrum, with your spectroscope, you can observe the lines of the Balmer series, especially the blue-colored line. Could you explain the electron transition that produces this line?

Implicit in the question Q1 is the idea that the observed lines are produced from the electron transition between the large number of atomic energy levels in an atom, and in Q2 is the idea that the blue line corresponds to the visible range of radiation and therefore the transition from a higher energy state to the state with quantum number 2.

DATA ANALYSIS AND RESULTS

Multiple-choice questions

We performed a dependent t-test that compared the mean difference between our samples (Field, 2013). Specifically, each correct answer was assigned 1 point. Thus, for a student who had answered correctly all the questions, the total maximum score was 10. The statistical analysis of the responses showed that the impact of the intervention on students' understanding was noteworthy, since the mean value and the standard deviation before the main implementation were M=1.55, SD=0.91, while after M=6.84, SD=1.70 respectively. The difference in performance, as evaluated using the statistical package SPSS 23, is statistically significant ($t=34.107$, $df=37$, $p<10^{-4}$). The results obtained from these three questions, before and after the intervention, are shown in Figure 5. High scores were attained after the intervention, and a noticeable improvement can be seen.

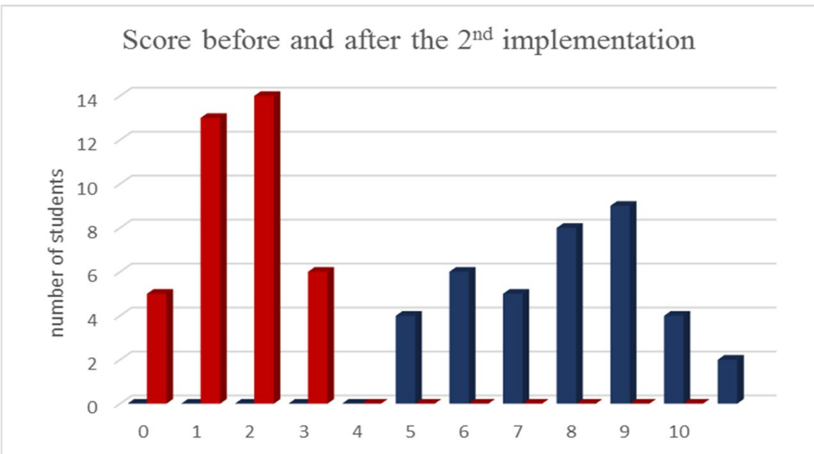

Figure 5. Distribution of students' scores for the overall test before and after the intervention.

The results of the students' responses to three questions of the multiple-choice questionnaire that we described above are presented in figure 6.

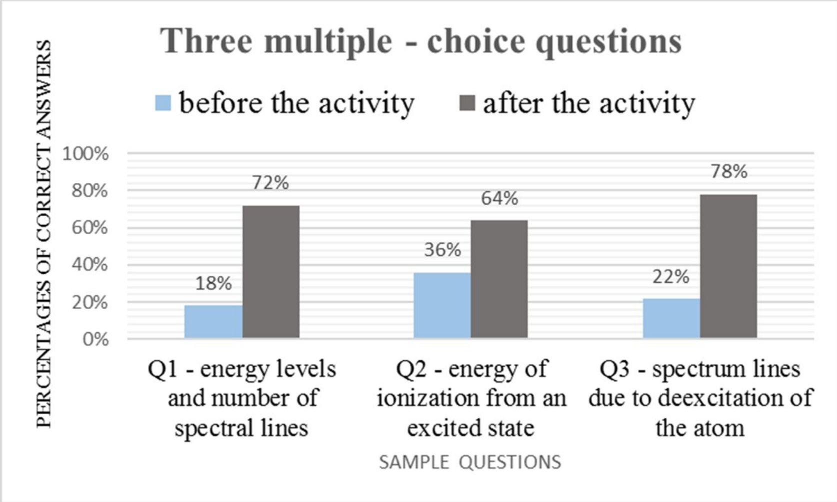

Figure 6. Percentages of students' correct answers to three questions before and after the teaching intervention.

Questionnaire with open-ended questions

The qualitative assessment of the data indicated that before the intervention, none of the students answered correctly. Only a small percentage of them were able to answer partially correct, due to their lack of knowledge, having many difficulties in answering the questions. After the intervention, students were able to answer correctly and partially correctly, achieving average scores of 24% and 34%, respectively, for question Q1 and average scores of 26% and 42%, respectively, for question Q2, as shown in Figure 7.

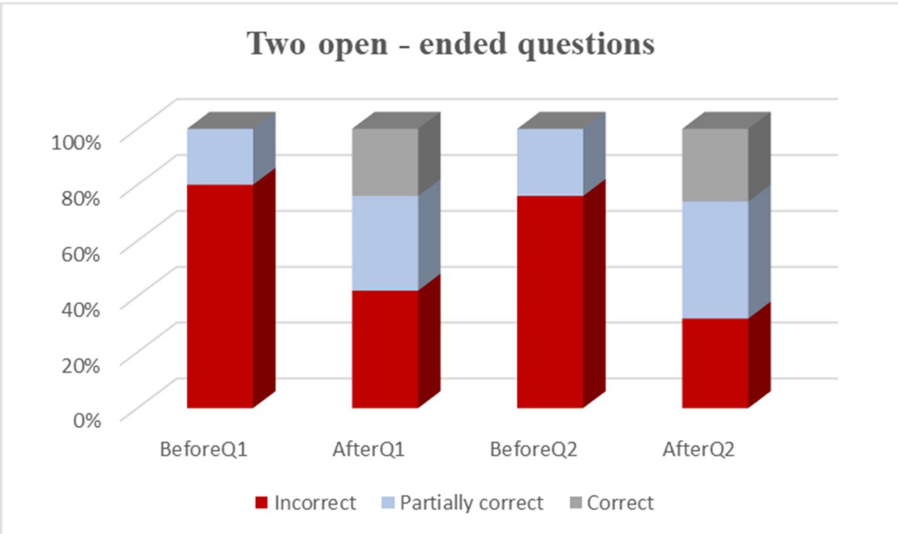

Figure 7. Quantitative assessment based on students' answers to the question Q1 before and after the implementation of the teaching module.

DISCUSSION

The present study provides an insight into how upper secondary students can be introduced to concepts and laws that describe the atomic energy levels of the model of the Bohr atom using the linear spectra of several light sources, including the linear spectra of the Sun and several chemical elements. The findings of the study create perspectives that the combination of the specific content with hands-on activities, simulations, and software and their application in the laboratory in astrophysical settings can be effective for the teaching of such complex and difficult concepts and laws in secondary education. Overall, teaching the physical quantities and equations of the model of the Bohr atom by studying line spectra, was fruitful. Nevertheless, our study continues with further applications for the improvement of the intervention as well as with investigations of the students' attitudes towards the implemented experimental procedures.

REFERENCES

Arons, A. B. (1990). *A guide to introductory physics teaching*. New York: Wiley.

Brown, D. (2020). *Tracker video analysis and modeling tool* (version 5.1.3) http://physlets.org/tracker/) (Accessed: 12 January 2020).

Duit, R., Gropengiesser, H., Kattmann, U., Komorek, M., & Parchmann, I. (2012). The model of educational reconstruction–A framework for improving teaching and learning science. In *Science education research and practice in Europe* (pp. 13-37). Brill Sense.

Field, A. (2013). *Discovering statistics using IBM SPSS statistics*. sage.

Hewitt, P. G. (2014). *Conceptual physics*. Pearson Higher Ed.

Ivanjek, L., Shaffer, P., Planinić, M., & McDermott, L. (2020). Probing student understanding of spectra through the use of a typical experiment used in teaching introductory modern physics. *Physical Review Physics Education Research*, *16*(1), 010102.

Kardaras, I., & Kallery, M. (2020). A teaching module for blackbody radiation using the continuous spectra of stars. *Physics Education*, *55*(4), 045010.

Savall-Alemany, F., Domènech-Blanco, J. L., Guisasola, J., & Martínez-Torregrosa, J. (2016). Identifying student and teacher difficulties in interpreting atomic spectra using a quantum model of emission and absorption of radiation. *Physical Review Physics Education Research*, *12*(1), 010132.

Serway, R. A., Moses, C. J., & Moyer, C. A. (2004). *Modern physics*. Cengage Learning.

Young, H. D., Freedman, R. A., Ford, A. L., & Zemansky, M. W. (2014). *Sears and Zemansky's University Physics*. Pearson

INTRODUCING THE CONCEPT OF ENERGY THROUGH HEAT AND TEMPERATURE BY MEANS OF INFRARED THERMAL CAMERAS

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The historical development of the concept of energy can be brought back to the early studies on heat by Mayer and Joule, suggesting that a unified treatment of heat, temperature and energy can be a possible route for teaching these complex subjects in an integrated way. We projected and experimented a learning path centred on the relation of the concepts of heat and temperature with the concept of energy and proposed it to a class of prospective primary school teachers (PPTs) in the framework of the Lab module of the course in Physics Education in a combined bachelor and master degree in Primary School Education in Italy. The intervention extends a previously developed approach based on the use of online sensors so as to highlight the concept of energy through the use of thermal cameras. In this work, we investigated how much the proposed path, activities and methodologies can help PPTs in learning and teaching the concepts of heat, temperature and energy as related to the use of online sensors and/or of thermal cameras. The study has been conducted through post-assessment questions, worksheets and final interviews.

Keywords: Infrared thermal cameras, Temperature, Energy

INTRODUCTION

Research literature has widely addressed the problem of how the concept of energy should be introduced and treated at the school level and the debate is still open [Heron 2014, Takaoglu 2018]. The importance of addressing it already at the primary school level has also been recognized [Heron 2009]. On another side, the historical development of the concept of energy can be brought back to the early studies on heat by Mayer and Joule [Coelho 2011], suggesting that a unified treatment of heat, temperature and energy can be a possible route for teaching and learning these complex subjects altogether. As a matter of fact, the concepts of heat and temperature have also been deeply investigated from the point of view of Physics Education [de Berg 2008]. To this respect, the use of infrared thermal cameras has recently acquired increasing interest [Haglund 2015].

In this context, we projected and experimented a learning path that allows introducing the concept of energy starting from the concepts of heat and temperature.

The formative module was proposed to a class of 65 prospective primary school teachers (PPTs) at the second year of the combined bachelor and master degree in Primary School Education of the Italian University of Verona [Monti 2021] and integrates content reconstruction and active learning strategies inside an experiential and situated modality [Berger 2008]. The activities were proposed as part of the laboratory module (1CFU) of the Physics Education course (9CFU). No previous treatment of the subject of Heat, Temperature and Energy was done in the Physics Education course.

The intervention is characterized by the use of thermal cameras inserted in a well-run previously developed approach [Michelini 2010, Daffara 2016] that was focused on the concepts of heat and temperature and centred on the usefulness of online sensors as compared to more traditional thermometers in teaching and learning heating as a process towards thermal equilibrium.

This study investigates how much the proposed path, activities and methodologies can help PPTs in learning and teaching the concepts of temperature, heat and, starting from these, the concept of energy, as related to the use of online sensors and/or of thermal cameras.

THE LEARNING PATH

The intervention was organized into four phases including interactive lectures and laboratory activities. The first and third phases were developed as interactive experiment-based lectures following active learning and inquiry-based strategies to introduce the operational definition of temperature, the concept of energy, and the sensors utilized for measuring the temperature. In the second and fourth lab-work phases, four experiments were autonomously carried out by the PPTs divided into groups: 1) heating of different masses of water with a boiler; 2) heating by irradiation with a halogen lamp; 3) thermal interaction of different masses of water; 4) Locke experiment. Experiments were performed in the Prediction - Experiment - Comparison modality using both a thermal camera and a system of four online sensors for real-time measurement of temperature. In particular, PPTs were introduced both to the qualitative and quantitative use of the pre-calibrated infrared thermal camera allowing the visualization as well as the measurement of 2D temperature maps.

First phase: introduction of the online sensors

In the first phase, we introduced the concept of thermal equilibrium and the operational definition of temperature through the use of 1D online sensors that allow real time simultaneous measurements of temperature using a graphical computer interface [Figure 1]. The instrument, called “Termocrono”, was developed at the Udine university [Michelini 2010].

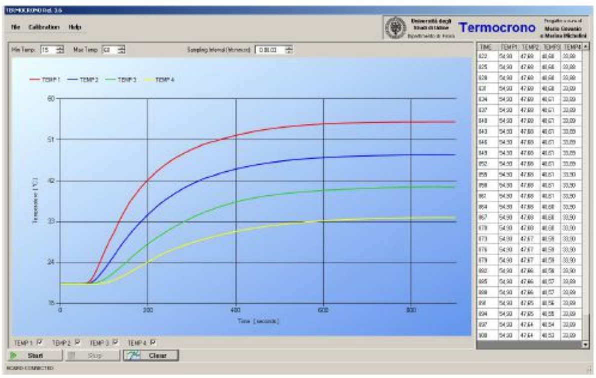

Figure 1. Graphical interface of the “Termocrono”.

Second phase: use of the online sensors

In the second phase, students were conducted into the concept of heating as a process leading to “increase of temperature” by autonomously carrying out two experiments in the Prediction-Experiment- Comparison (PEC) modality using the online sensors: 1) heating of water with a boiler; 2) heating of water by irradiation with the light emitted by a halogen lamp [Figure 2].

Figure 2. Heating of water by irradiation with a halogen lamp.

Third phase: introduction of the thermal camera

In the third phase, starting from the results of the former irradiation experiment with the halogen lamp, students were interactively guided into the concept of energy as "what is capable of heating", to associating the concept of "amount of heating" with the concept of "transferred energy", and to recognizing that light carries energy.

At this point, the thermal camera was introduced as a two-dimensional remote sensor of the energy emitted by all bodies in the form of non-visible (infrared) light which is in turn related to the measurement of temperature. In particular, students experienced the possibility of "viewing" themselves in darkness conditions.

In our intervention, we utilized a FLIR C2 thermal camera [Figure 3] equipped with a bolometric sensor (80x90 array) sensitive in the long IR range 8-14 micron and calibrated in temperature. The FLIR camera acquires also a visible image (320x240 pixels) superimposed to the thermogram. An interesting option for this proposal is the possibility of visualizing in real-time on the display the thermogram, the visible, or a blending of the two images.

Figure 3. The FLIR C2 thermal camera.

Fourth phase: use of the thermal camera

In the fourth phase, students first repeated the two experiments done in the second phase using the thermal camera in place of the online sensors. Then, they carried out two other experiments, always in the PEC modality, using both the online sensors and the thermal camera: 3) thermal interaction of different masses of water, reaching thermal equilibrium and 4) the so called "Locke experiment" about thermal sensation [Michelini 2010, Daffara 2016] [Figure 4]: given three glasses of warm, hot and cold water, fingers first immersed in hot water and then in warm water feel it cold, while fingers first immersed in cold water feel warm water as hot.

Finally, students were also lead to explore with the thermal camera the increase in temperature of a current carrying wire and the process of heating a surface by friction: these experiences allow opening the way to extend the concept of heat and energy to other fields of physics such as mechanics and electrical phenomena.

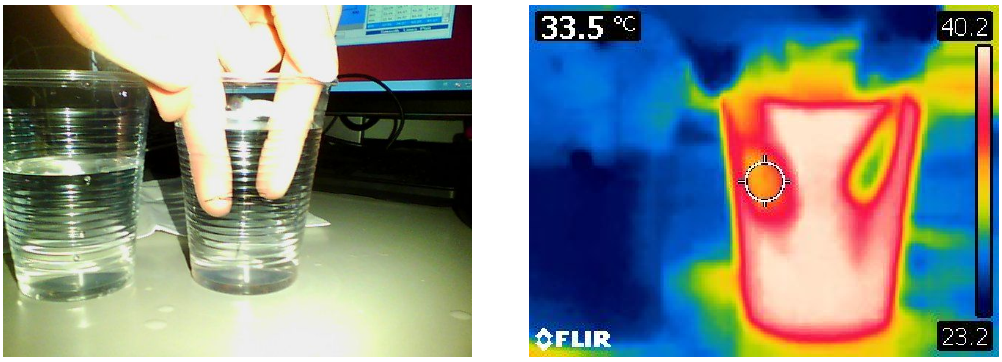

Figure 4. Locke experiment using the thermal camera.

The learning path ended with final considerations that emerged from the discussion with the students conducted in an interactive guided modality (a kind of Socratic conversation):

- measuring temperature means “finding a way of associating a number to a state of thermal equilibrium”
- heating means “causing an increase of temperature"
- heating is energy transfer
- heating can be obtained through conduction, convection and irradiation
- thermal sensation is related to the rapidity of heating or cooling
- heat is transferred energy related to heating or cooling
- temperature is a measure of an energy which is internal to bodies (internal energy)

RESEARCH METHODS

This study has been conducted through post-assessment questions, worksheets and final interviews addressing the following points.

In the post-assessment questions, PPTs were asked which ways they know for measuring temperature. In the worksheets, they were asked to plan a learning path on thermal phenomena highlighting the addressed concepts and the corresponding related activities. Final interviews were mainly focused on whether and how PPT used or would use a thermal camera in their proposed activities and, if so, related to which concepts.

Based on PPTs' answers we investigated how much the utilized learning path and methodologies can help PPTs in understanding the proposed concepts through the following research questions:

1) Do PPTs cite (in the proposed post-assessment question) thermal cameras among the possible instruments for measuring temperature?

2) Which concepts and corresponding activities do PPTs choose (in the worksheets) in constructing the proposed educational path on thermal phenomena?

3) Do (from the worksheets) or would (from the final interviews) - PPTs propose the use of thermal cameras in their activities and, if so, related to what concepts?

RESULTS

Qualitative data analysis was performed focusing: a) on the instruments (online sensors and thermal cameras) as cited in the post-assessment questions and as utilized in the activities proposed in the learning path by PPTs for their pupils; b) on the concepts addressed by PPTs as related to the instruments utilized in the activities.

The addressed concepts were grouped into three main categories that were identified from students' answers given in the worksheets as well as in the final interviews as particularly meaningful for the purposes of the present investigation: temperature/thermal equilibrium/thermal sensation; heat and energy; heating through irradiation.

Use of the online sensors

In the post-assessment questions, the "Termocrono" is cited among the possible instruments for measuring temperature by almost all the 65 students (64/65); in the planned didactic path, it is utilized by 41/64. Among these: 37/41 propose it for introducing the concept of temperature through the difference between thermal equilibrium and thermal sensation; 28/41 for addressing the concept of heating through irradiation; 26/41 propose its use for both these purposes [Figure 5].

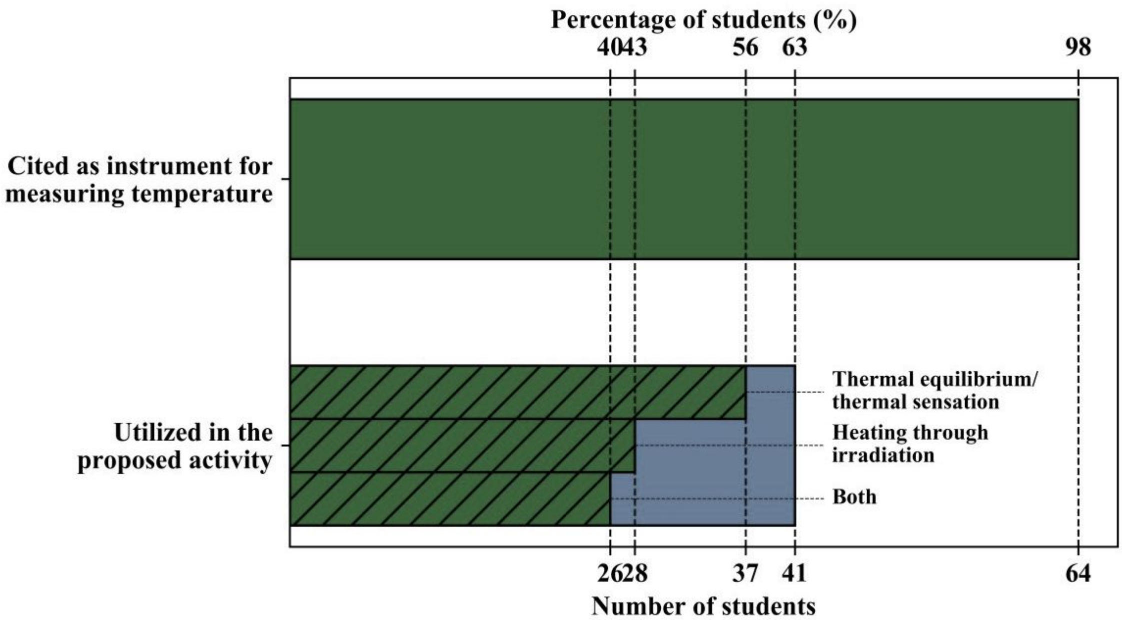

Figure 5. Use of the "Termocrono".

Use of the thermal camera

The thermal camera is less cited (42/65) than the "Termocrono" among the possible instruments for measuring temperature; in the planned didactic path, the thermal camera is utilized (or would be possibly utilized if available, as it emerged from the interviews) - always for visualization purposes- by 28/42, of which 13/28 for addressing the concept of heating through irradiation and 19/28 for introducing the concepts of heat and energy; 8/28 propose its use for both these purposes [Figure 6].

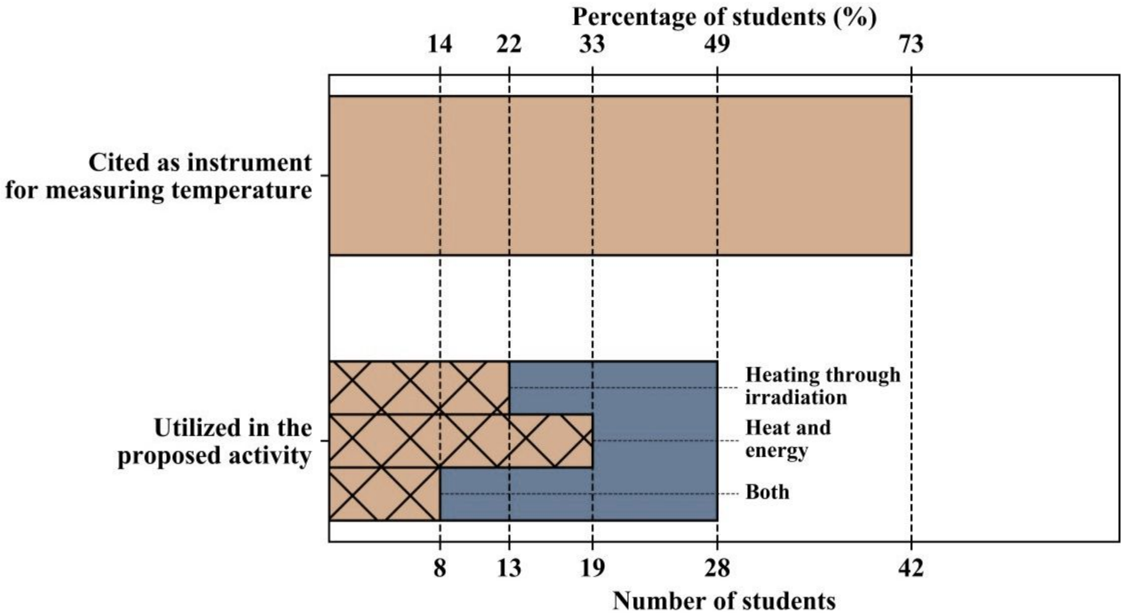

Figure 6. Use of the thermal camera.

Addressed concepts

From the point of view of the treated concepts, our analysis pointed out three most significant aspects [Figure 7].

The comparison between temperature and thermal sensation is addressed by 57/65 and is associated to the use of the "Termocrono" by 37/57. In the other cases, the use of more traditional thermometers is foreseen. The comparison between temperature and thermal sensation is never associated to the use of a thermal camera.

The process of heating through irradiation, addressed by 43/65, is associated to the use of both the "Termocrono" (28/43) and the thermal camera (13/43): in the case of the thermal camera, 6/43 actually proposed an activity while 7/43 would possibly propose it if the thermal camera would be available in the classroom, as it emerged from the interviews.

Heat and energy are considered as important concepts to be treated in an educational path by 28/65. Of these, a total of 19/28 actually proposed (only 7/28), or would possibly propose (12/28) an activity with the thermal camera if it would be available in the classroom: the remaining 9/28 proposed either an alternative visualization with sawdust or ink or even no activities at all. The concepts of heat and energy are never associated to the use of the "Termocrono".

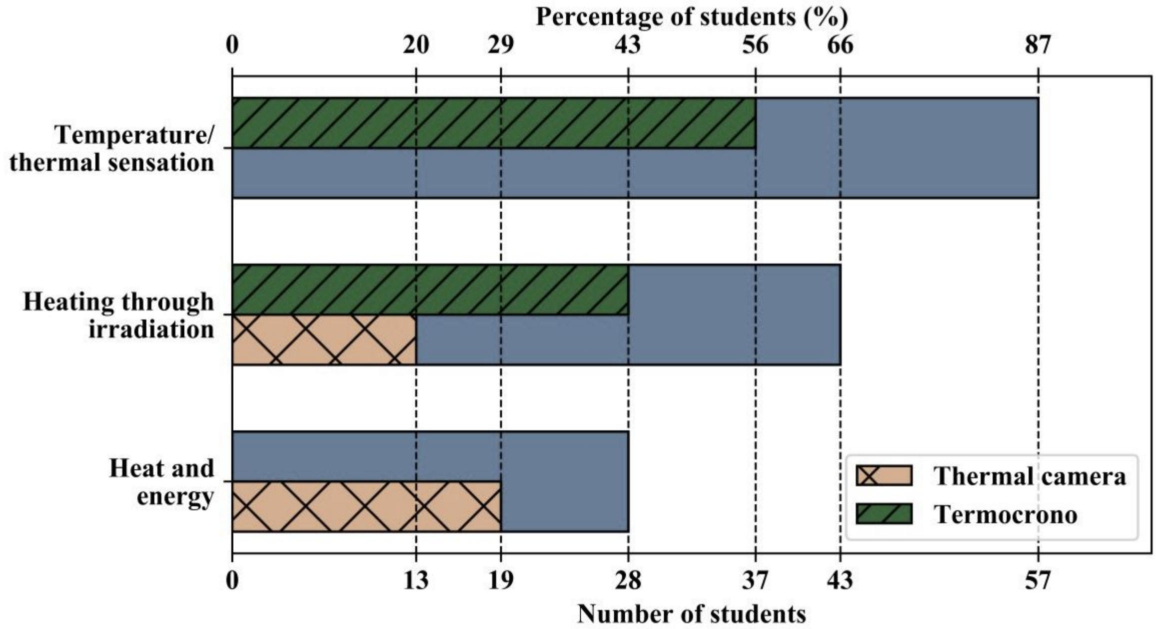

Figure 7. Addressed concepts and instruments proposed for related activities.

DISCUSSION

Two general considerations emerge from our study.

The first one, more practical, is that typically PPTs consider the thermal camera as an expensive specialistic instrument, not easy to be found in school: this is the main reason why they tend not to propose its use in their worksheets.

The second and more fundamental one is that we found an exclusive correspondence between addressed concepts and chosen instruments, which seems to be based on the fact that, differently from the online sensors, thermal cameras have been considered as instruments for *visualization* purposes rather than a radiometer for *measuring* temperature, although the possibility of measuring temperature with a thermal camera has been experimented in the laboratory activities.

The activities that PPTs would propose to pupils are mainly concentrated on the concepts of thermal equilibrium, temperature and thermal sensation with a corresponding use of online sensors (strongly preferred as compared to more traditional thermometers) that excludes thermal cameras. This suggests that the comprehension of heating and cooling as *processes* leading to a common equilibrium state is better gained using the online sensors, indicating that these processes are better understood in terms of *measuring temperature*.

When the concepts of heat and energy are addressed in the planned educational path, there is a corresponding use of the thermal camera that excludes online sensors (and traditional thermometers as well). This suggests that the comprehension of heat in terms of *energy transfer* is more easily grasped through *visualization* using a thermal camera. As a matter of fact, in parallel to their tendency to discard the use of thermal cameras - not so much because they do not understand its use or its didactic potentialities, but rather due to its cost and to the supposed difficulty of having it in a primary school classroom – PPTs tend to omit addressing the concepts of heat and energy transfer, which they consider particularly difficult for children.

Finally, the concept of heating through irradiation was understood by PPTs both in terms of measuring temperature (use of the online sensors) and in terms of energy transfer (visualized through the thermal camera) showing that this process indeed allows introducing the association between temperature, heat and energy.

CONCLUSIONS

On the practical level this study confirms that the proposed approach including the use of a thermal camera can indeed be useful in helping primary school teachers in the task of introducing the concept of energy at the primary school level (otherwise considered too difficult), because thermal cameras allow associating the concept of energy to the concept of heat (which is, in turn, related to a variation of temperature) through the related experimental activities. In this respect, the advent of more recent low-cost thermal cameras, such as those designed for smartphones, could make this potentially successful approach more appealing.

From a more fundamental point of view, understanding this result requires to investigate at the cognitive level the reasons of the exclusive correspondence between addressed concepts and instruments highlighted in the previous sections. To this aim, we can let ourselves be guided by the key word used, repeated and stressed by PPTs in the assessment questions as well as in the worksheets and in the interviews: *visualization*.

The thermal camera allows the experimental 2D **visualization** of heating in terms of **flow** of **an abstract physical entity** (energy), regardless of any numerical value. The online 1D sensor allows the graphical representation of heating as a **process** where **a numerical value** (temperature) **changes** in time, but it misses the idea of flow, which is a common feature of heat and energy since heat is energy flow.

Therefore, what emerges from our data is the key point of the centrality of the idea of *flow* and of an *abstract entity that is transferred and exchanged,* to the concept of energy and heat; abstract entity of which, in a certain sense, the thermal camera allows the visualization.

In this perspective, our findings suggest that the proposed didactic approach, based on a unified treatment of temperature, heat and energy, is grounded at the cognitive level. The historical evolution itself of the concepts of heat and energy, cited in the introduction, can be likewise brought back to the same cognitive level. To deepen this fundamental aspect, we are planning an incoming future work that integrates didactics and history of physics focused on the concept of energy also beyond thermal phenomena, extending it as a unifying concept to different fields of physics, as partially mentioned in the intervention proposed for the present study.

REFERENCES

Berger H., Eylon B-S, Bagno E. (2008) Professional Development of Physics Teachers, *J. Sci Educ Technol*,17:399-409

Coelho R.L. (2011) On the Concept of Energy. In: Kokkotas P.V., Malamitsa K.S., Rizaki A.A. (eds) Adapting Historical Knowledge Production to the Classroom. SensePublishers

Daffara C., Michelini M, Monti F, Santi L, Stefanel A (2016) Laboratory for teacher education based on ICT: the case of thermal phenomena, presented at the GIREP 2016 Seminar, August 30 - September 3, 2016, Krakow, Poland

de Berg K. (2008) The Concepts of Heat and Temperature: The Problem of Determining the Content for the Construction of an Historical Case Study which is Sensitive to Nature of Science Issues and Teaching–Learning Issues, *Sci & Educ*, 17-75

Haglund J., F. Jeppsson, D. Hedberg, K.J. Schonborn (2015) Students' framing of laboratory exercises using infrared cameras, *Physical review special topics—physics education research* 11, 020127

Heron P., Michelini M. and Stefanel A. (2009) Teaching and learning the concept of energy in primary school, *Frontiers in Science Education Research* - Conference Proceedings

Heron P., Michelini M (2014) Teaching about energy. Which concepts should be taught at which educational level? GIREP-ICPE-MPTL 2010, Reims 22-27 August 2010, Lithostampa (Udine) 284-285

Michelini M., Santi L, Stefanel A. (2010) Thermal sensors interfaced with computer as extension of senses in kindergarten and primary school, in *Multimedia in Physics Teaching and Learning*, Michelini M, Lambourne R, Mathelisch L *Il Nuovo Cimento*, 33(3) 171-179

Monti F. and Daffara C. (2021) heat, temperature and energy: a formative experiment-based module including the use of infrared cameras, *J. Phys: Conf. Ser. 1929 012020*

Takaoglu Z.B. (2018) Energy Concept Understanding of High School Students: A Cross-grade Study, *Universal Journal of Educational Research* 6(4): 653-660

IS ARAÇÁ BAY DEAD? A DIDACTIC SEQUENCE IN A SCIENCE-TECHNOLOGY-SOCIETY-ENVIRONMENT PERSPECTIVE

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The Biota/FAPESP Program (BFP), created in March 1999, is considered one of the largest biodiversity programs in Brazil. However, BFP failed to translate scientific advancements into teaching material to be used by schools. To fill this gap, a thematic project was conceived entitled "The Biota-FAPESP program in basic education: possibilities for curricular integration" (BFP-BE), whose main objective is to promote actions aimed at the use and dissemination of data generated by the BFP. In this work, we describe a didactic sequence to improve Brazilian students' knowledge regarding marine biodiversity. We choose the database from one of the major projects in the marine area, Biota/FAPESP - Araçá (BFA): "Biodiversity and functioning of a subtropical coastal ecosystem: support for integrated management", due to its valuable contributions to marine science as well as conservation and marine management. As BFA demonstrated how the advancement of scientific knowledge on biodiversity and how its socio-economic relevance is essential to improve the legal instruments, our material was developed in a Science-Technology-Society-Environment (STSE) perspective. The databases from the projects "Relevance of Science Education" (ROSE) and "Student Knowledge in the International Perspective: Evolution, Nature, and Society" (SAPIENS) were also used as a guide to apply the real demands and interests of students from different Brazilian regions. The didactic sequence, entitled "Is Araçá Bay dead?", is composed by three main sections regarding: i) to explore what students know about the marine environments, particularly a bay; ii) to present and discuss the Social-Scientific Issue (the expansion of the São Sebastião Port using the Araçá Bay) as well as to discover the marine biodiversity of Araçá Bay; and iii) to assess what students have learned.

Keywords: Interdisciplinarity, Problem Solving, Socio-Scientific Issues; Native biodiversity

INTRODUCTION

The Biota/FAPESP Program (BFP), created in March 1999, is considered one of the largest biodiversity programs in Brazil in conservation issues. However, BFP failed to translate scientific advancements into teaching material for use in schools (Joly et al., 2010). To fill this gap, there has been a public call for specific educational projects in the summer of 2016, and the project entitled "The BIOTA-FAPESP program in basic education: possibilities for curricular integration" (BFP-BE) was qualified. Its main objective is to promote actions aimed at the use and dissemination of data generated by the BFP.

One of the BFP-BE research lines explores Brazilian students' knowledge regarding marine biodiversity, trying to identify possible gaps and expectations, using the large BFP database to plan didactic materials to address those needs. For this proposal, we chose the database from one of the major projects in the marine area, Biota/FAPESP - Araçá (BFA): "Biodiversity and functioning of a subtropical coastal ecosystem: support for integrated management", due to its valuable contributions to marine science as well as conservation and marine management.

The BFA aimed to understand how the coastal zone behaves as a complex system, considering the integration between physical, biological, and social processes within the Araçá Bay (located on the Northern Coast of São Paulo State, Brazil), such as sediment circulation and transport, food webs, energy and matter fluxes, and fishing production and activity (Amaral, Turra, Ciotti, Rossi-Wongstschowski, & Schaeffer-Novelli, 2016). After many pieces of research, scientists concluded that Araçá Bay hosts one of the most environmentally diverse areas along the Brazilian coast, which gives it significant ecological importance, and it is fundamental for the sustainability of caiçaras families (traditional inhabitants) and the maintenance of their cultural identity (Amaral, Migotto, Turra, & Schaeffer-Novelli, 2010; Amaral et al., 2016).

We believe that these data generated by the BFA can support educational moments of interdisciplinary connections, including Science-Technology-Society-Environment (STSE), that can illustrate Socio-Scientific Issues (SSI). They often involve controversies and both scientific information and value judgments, stimulating functional scientific literacy and students' understanding of the nature of science (Sadler & Zeidler, 2005). Our aim is to use the database generated by the BFA to produce teaching and learning materials, taking into account the real demands and interests of Brazilian students in addition to being able to assist in the Scientific Literacy process and provide a citizen formation.

METHOD

We conducted a literature search up looking for records about Araçá Bay as well as BFA published until December 2020. The following databases and literature sources were consulted: Google, Google Scholar, ResearchGate, and *Biblioteca Virtual da FAPESP* (Research Supported by the São Paulo Research Foundation - FAPESP). In addition, the results of studies on the interests, attitudes, and knowledge about science and technology among young Brazilian students were analysed: "Relevance of Science Education" (ROSE) and "Student Knowledge in the International Perspective: Evolution, Nature, and Society" (SAPIENS) (Franzolin, Garcia, & Bizzo, 2020). These databases serve as a baseline for a better understanding of the real demands and interests of students from Brazil.

RESULTS

One major subject of demand and interest of students from Brazil pointed by Franzolin et al. (2020) was chosen: "How people, animals, plants, and the environment depend on each other?". Araçá Bay has a complex network involving a thousand species of organisms in addition to the human population. We aim to emphasize the bay as fundamental for the sustainability of caiçaras families (traditional inhabitants) and the maintenance of their cultural identity. This information will be significant to show students the close relationship between people and many different forms of life.

The teaching material was produced in a STSE perspective (Auler & Bazzo, 2001; Carmona & Vieira, 2017) and the SSI defined as a controversial problem was the expansion of the São Sebastião Port (SSP) because it will be necessary to landfill (partial or total) the Araçá Bay.

The material was projected to be used for students of the last year of Brazilian primary education (age 14–15 years), taking into account the *Base Nacional Comum Curricular*, the new Brazilian 'common core' curriculum known as the BNCC (Brasil, 2018). The thematic unit is "Life and Evolution", and the object of knowledge is biodiversity preservation. The first version of the teaching material is presented below, which will still undergo evaluation by primary school teachers.

Teaching material: "Is Araçá Bay dead?"

The title "Is Araçá Bay dead?" intended to be attractive and reflect the content and training intentions. Altogether, it contains 11 lessons (each lasting 45 minutes), which are organized into three main sections. Figure 1 represents the main steps.

The first section aims to find out what students know about the theme "seas and oceans". For this, a diagnostic questionnaire was constructed with the following questions: 1) When thinking about the seas and oceans, what words come to your mind? 2) What did you learn in your school about seas and oceans? 3) Is there any relationship between your daily life and the seas and oceans? Justify. 4) Is there any topic related to the seas and oceans that you are interested in studying? If yes, which one? After, the teacher will be able to present a photo board of the main marine environments (Figure 1A) and ask students several questions, such as what these environments have in common and what differentiates them (e.g., abiotic components). This will be a good opportunity to introduce students to an unfamiliar environment, the bay.

The second section aims to present the Socio-Scientific Issue as well as encourage students to reflect on the causes and consequences of impacts in the coastal region. For the first activity, entitled "Knowing the problem to be investigated", it is proposed that students read the first text adapted from Xavier, Stori, and Turra (2016) and Florio (2017). Subsequently, students will participate in a debate with the following guiding questions: 1) In your opinion, what would happen to this ecosystem (Araçá Bay) if the São Sebastião Port is expanded? 2) What would be the environmental impact of expanding the São Sebastião Port using piles and slabs on Araçá Bay?

For the second activity, entitled "Discovering the Araçá Bay", it is proposed that students read the second text adapted from Andrade (2015) and Amaral et al. (2016). This text contains a description of the biodiversity of the Araçá Bay and presents the Biota/FAPESP - Araçá project. In the text, there is two photos with several marine organisms registered in Araçá Bay (Figure 1B and 1C). From the detailed observation of the photo, the teacher can discuss with students on various topics such as biodiversity and ecosystem. To finish the activity, students will watch a part of the video "Pulsante | A film about Araçá Bay" (**Figure 1D**, https://youtu.be/HneSn9Pu0iA, video time to watch: 0 to 13 minutes) and then discuss the question: "Is Araçá Bay dead?".

For the third activity, entitled "The expansion of the São Sebastião Port: possible consequences", it is proposed that students read the third text adapted from Andrade (2015). Then, students will participate in a debate with the following guiding questions: 1) What would be the problems caused by the expansion of the São Sebastião Port using slabs on the Araçá Bay? 2) Some researchers are against, and others are in favor of this expansion. What are their arguments, and which would you agree with? Justify your choice. Finally, the students can watch the last part of the video "Pulsante | A film about Araçá Bay" (video time to watch: 13 to 25 minutes).

For the fourth activity, entitled "Getting to know the people who live in/from Araçá Bay", it is proposed that students read the fourth text adapted from Amaral et al. (2016), referring to Chapter III Resource Management. Afterwards, students will participate in a debate with the following guiding questions: 1) With the expansion of the São Sebastião Port, using Araçá Bay, what will happen to the caiçaras families there? 2) Why is it important to know to protect? As a conclusion of the activity, it is proposed that students make a video or write a letter in defense of Araçá Bay.

The third section aims to assess what students have learned. Three questions were elaborated: a multiple-choice question, a true/false question, and an exercise to complete sentences.

Figure 1. Representation of the main steps of the teaching material. A) Photo board with main marine environments; Authors: Renata Alitto (*oceano*, *mar*, *costão rochoso* and *praia*); Gabriel Monteiro (*baía*);

Guilherme Abuchahla (*manguezal*). **B)** Polychaete (sea-worm, *Branchiomma luctuosum*), with intense and exuberant color, abundant on the rocky shores; Author: Gabriel Monteiro. **C)** Ophiuroidea (brittle star, *Hemipholis cordifera*); Author: Renata Alitto. **D)** Video Pulsante | A film about Araçá Bay, available on https://youtu.be/HneSn9Pu0iA.

DISCUSSION

The STSE perspective was chosen to produce a teaching material using Araçá Bay as an educational resource. This can be an efficient strategy to address socio-environmental problems (Auler & Bazzo, 2001; Sadler & Zeidler, 2005) such as that pointed out by the thematic project Biota/FAPESP - Araçá (BFA): the expansion of the São Sebastião Port.

The teaching material has 11 lessons organized into three main sections aiming: 1) to find out what students know about the theme "seas and oceans"; 2) to present the Socio-Scientific Issue as well as encourage students to reflect on the causes and consequences of its impacts in the coastal region; 3) to assess what students have learned. Altogether, four texts (which comprise the second section) were written considering the target audience of students (ages 14–15 years).

Several photos of marine environments, including Araçá Bay, as well as marine biodiversity were chosen to compose the teaching material, making it more illustrated and more attractive. An illustrated material will enable the visualization and recognition of environments and marine biodiversity, which unfortunately, are difficult to access for most Brazilian people.

The didactic material was made according to the BNCC in the thematic unit "Life and evolution" since there is no specific unit for "Ocean Literacy" (OL). OL is defined as the understanding of the ocean's influence on human beings and vice versa. It aims to improve knowledge on marine environments, enabling citizens to make responsible decisions concerning marine-related issues (Santoro, Santin, Scowcroft, Fauville, & Tuddenham, 2020).

Despite all this importance, OL is not valued in Brazilian curricula. In a recent study, Pazoto, Silva, and Duarte (2022) pointed that the representativeness of OL in Brazilian documents is below the recommended for a person to be considered ocean literate, especially for topics dealing with environmental risks in coastal zones. The authors also concluded that actions aimed at expanding the presence of OL principles and concepts in Brazilian school curricula must be taken.

For students to be able to assess the Socio-Scientific Issue presented in our material, it is necessary that they know and understand the importance of marine environments and their biodiversity. Addressing these topics has become increasingly important especially towards the study of marine biodiversity.

Unfortunately, there are no nationally representative studies to recognise how much teachers emphasize Brazilian biodiversity in their classrooms. However, a recent exploratory study carried out with 147 teachers (Araújo & Alitto, 2021) found that there is little emphasis on this topic. According to these interviewed teachers, the absence of adequate teaching materials was pointed as a common factor that negatively affect the teaching of native biodiversity.

In Brazil, learning materials are distributed by the Ministry of Education and they are the same for all schools. Therefore, it is easier to find pictures of large, exotic, charismatic megafauna (e.g., polar bears, elephants, etc.) rather than native South American animals and plants in the bestselling biology textbooks (Oliveira & Cook, 2019). This condition does not reflect the demand of Brazilian students, who are interested in learning about the fauna and flora in their area (Franzolin et al., 2020).

Therefore, produce and share the didactic material about Araçá Bay is relevant since it can help to fill the gap in the teaching of biodiversity in Brazil. Moreover, the material can be used by teachers and students from all over the country including those close to Araçá Bay, who which study the native biodiversity of other places and not where they live.

The next step is to apply the material in a single Brazilian public school, test, improve, and then it will be available to Brazilian and foreign schools. Other subjects published by Franzolin et al. (2020), papers, videos, and news reports regarding the BFA are being studied and, if necessary, they will be used to improve or produce new sequences. All the didactic sequences (for both teachers and students) will be available on the Portal EDEVO-Darwin (https://sites.usp.br/edevodarwin/).

Considering that 2022 is the second year of the Decade of Ocean (proclaimed by the United Nations), using a small bay as Araçá in the classroom is an ideal opportunity to show how the management of our oceans and coasts is important for the conservation of biodiversity. As a result, we expect students to have an increase in their critical thinking and effective attitudes to solve problems related to marine biodiversity.

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REFERENCES

Amaral, A. C. Z., Migotto, A. E., Turra, A., & Schaeffer-Novelli, Y. (2010). Araçá: biodiversidade, impactos e ameaças. *Biota Neotropica, 10*(1), 219–264. doi:10.1590/s1676-06032010000100022

Amaral, A. C. Z., Turra, A., Ciotti, A. M., Rossi-Wongstschowski, C. L. D. B., & Schaeffer-Novelli, Y. (2016). *Life in Araçá Bay: diversity and importance* (3rd ed.). São Paulo: Lume.

Andrade, R. d. O. (2015). Na lama e na areia do Araçá. *Revista FAPESP, 234*, 58–61.

Araújo, L. A. L., & Alitto, R. A. S. (2021). Teaching native biodiversity: an exploratory study with Brazilian teachers. *Journal of Biological Education*, 1–11. doi:10.1080/00219266.2021.2006271

Auler, D., & Bazzo, W. A. (2001). Reflexões para a implementação do movimento CTS no contexto educacional brasileiro. *Ciência & Educação, 7*(1), 1–13.

Brasil. (2018). *Ministério da Educação e Desporto. Base Nacional Comum Curricular*. Brasília.

Carmona, I. V., & Vieira, M. V. (2017). Ciência, Tecnologia e Sociedade e Educação Ambiental: Uma Revisão Bibliográfica em Anais de Eventos Científicos da Área de Ensino de Ciências. *Revista Ciências & Ideias, 8*(3), 94–114. doi:10.22047/2176-1477/2017.v8i3.752

Florio, R. C. (2017). Ampliação do porto de São Sebastião: múltiplas faces do mesmo problema ambiental. Retrieved from http://aun.webhostusp.sti.usp.br/index.php/2017/06/13/ampliacao-do-porto-de-sao-sebastiao-multiplas-faces-do-mesmo-problema-ambiental/

Franzolin, F., Garcia, P. S., & Bizzo, N. (2020). Amazon Conservation and Students' interests for biodiversity: the need to boost science education in Brazil. *Science Advances, 6*, eabb0110. doi:10.1126/sciadv.abb0110

Joly, C. A., Rodrigues, R. R., Metzger, J. P., Haddad, C. F. B., Verdade, L. M., Oliveira, M. C., & Bolzani, V. S. (2010). Biodiversity Conservation Research, Training, and Policy in São Paulo. *Science, 328*(5984), 1358–1359. doi:10.1126/science.1188639

Oliveira, A. W., & Cook, K. (2019). *Evolution Education and the Rise of the Creationist Movement in Brazil*. Lanham: Lexington Books.

Pazoto, C. E., Silva, E. P., & Duarte, M. R. (2022). Ocean literacy in Brazilian school curricula: An opportunity to improve coastal management and address coastal risks? *Ocean & Coastal Management, 219*, 106047. doi:10.1016/j.ocecoaman.2022.106047

Sadler, T. D., & Zeidler, D. L. (2005). Patterns of informal reasoning in the context of socioscientific decision making. *Journal of Research in Science Teaching, 42*(1), 112–138. doi:10.1002/tea.20042

Santoro, F., Santin, S., Scowcroft, G., Fauville, G., & Tuddenham, P. (2020). *Cultura Oceânica para todos: kit pedagógico*. França: UNESCO.

Xavier, L. Y., Stori, F. T., & Turra, A. (2016). *Desvendando os Oceanos: Um Olhar Sobre a Baía do Araçá*. São Paulo: Instituto Oceanográfico da Universidade de São Paulo.

TEACHING GENETICS USING THE SIMPSONS. AN INNOVATIVE PROPOSAL WITH SPANISH PRE-SERVICE SCIENCE TEACHERS

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Television and internet often include science-related content that may affect consumers. As such, they may be good teaching-learning resources. With this is mind, this study presents the results of an activity based on use of the well-known TV series "The Simpsons" to teach genetics. This proposal was implemented with 24 pre-service science teachers (PSTs) studying the Masters in Secondary Education Teaching at the University of Malaga (Málaga, Spain), in the Biology and Geology field, as part of an educational innovation course in the academic year 2020-2021. The study was carried out in the classroom as follows. Using a family tree for the Simpsons family containing three generations, the PSTs were asked to design an activity for secondary students using the laws of Mendelian inheritance. They were given 30 minutes to discuss different proposals as a group and then presented their designs. Finally, they completed a questionnaire to evaluate different aspects of the activity. The proposals to explain the family tree were based on the characteristics of hair colour and hair type. Hair colour generated significant debate as it proved difficult to explain all the phenotypes. However, they chose an autosomal recessive explanation assuming that other possible factors were likely involved. The hair type characteristic was explained using an intermediate inheritance. The evaluations of the PSTs were very favourable, with the questionnaire reflecting the ease of design and implementation and the marked versatility. Indeed, activities based around TV series were considered to be effective for teaching science. However, this resource must be adapted to the age group, interests and context of the students in which it is to be implemented

Keywords: TV series, pre-service science teachers, task design

INTRODUCION

Media such as television and the internet are widely used in the general population due to their widespread availability, consumption and ability to influence (AIMC, 2018). Various authors have investigated the benefits of using fiction resources such as films, TV programmes, series, stories or novels to teach science (Fraknoi, 2002; Franco-Mariscal, 2021; Hasse, 2015; Hamalosmanoglu, Kizilay & Saylan Kirmizigül, 2020; Kilby-Goodwin, 2010; Koutnikova, 2017). These resources may help to create mental images that can be correlated with an underlying scientific theory, may help to understand abstract concepts, are very visual, fun, improve the applicability of the content learned or enhance the interest in learning science, amongst other advantages (Barnett & Kafka, 2007). According to Evrekly, Inel and Balim (2011), "concept cartoons can be defined as visual aids in which the opinions and discussions of cartoon characters regarding the cause of or solution for a daily life event are presented in written form in speech bubbles".

Biology-related topics appear frequently in these resources. Examples include Jurassic Park, GATTACA, The Martian, Planet of the Apes, an inconvenient truth, Twenty Thousand Leagues Under the Seas, Frankenstein or The Walking Dead, all of which have plots with a biological origin (Barnett & Kafka, 2007). Fiction often presents concepts, situations or ideas related to actual science that cause spectators to think and ask themselves whether it is possible for these to happen in real life (Rose, 2003).

Genetics shows us the strong link between science and society. As well as being present in these resources, genetics is also present in our lives. In addition to genetic inheritance issues related to physical characteristics or hereditary diseases, other examples where its importance is reflected are blood donations, gene editing, compatibility in organ donation, among others. Understanding the scientific basis of these issues helps our students to build critical opinions on these topical issues (López-Fernández & Franco-Mariscal, 2019).

An example of genetics can be studied in the TV show Game of Thrones with the sequence of rescue of the dragon from the ice, where you can see that the colour of his eyes changes to blue (Franco-Mariscal, Cano-Iglesias & Hierrezuelo-Osorio, 2020). This sequence allows to discuss different contents about genetics through driven questions. Some driven questions could be: *Why do some dragons have blue eyes and another brown?,* or can two dragons with brown eyes have a dragon with blue eyes? If so, why?

This study makes use of The Simpsons series to learn genetics, a cartoon that has already been used successfully by other authors (Orthia et al., 2012; Perales & Vílchez, 2005). This work presents the results of an activity with pre-service science teachers (hereinafter, PSTs), who were asked to design an activity for secondary students to provide a genetic explanation for the characteristic observed in the Simpsons family.

METHOD

A total of 24 students studying the Masters in Secondary Education Teaching at the University of Malaga (Málaga, Spain), in the Biology and Geology field, participated in this activity. Of these, 58.3% were male and 41.7% female. The activity was performed remotely in a session lasting two hours as part of the "Teaching innovation and introduction to educational research" subject in the academic year 2020-21. The innovation proposed is based on the use of fiction series to teach science.

The Simpsons is an internationally renowned TV series. It is an American comedy series that has been broadcast daily in Spain for many years. The Simpsons is about the life and day-today life of a middle-class family. The PSTs were provided with a family tree for the Simpsons family that included the parents (Homer and Marge), their siblings (Herb, Patty, and Selma), their children (Bart, Lisa and Maggie) and the grandparents (Abraham, Mona, Clancy and Jackie). They were then asked to design an activity for secondary students that could be used to explain inheritance and transmission of genetic characteristics in this family using Mendel's laws, which is one of the objectives included in the Spanish secondary curriculum. The PSTs worked in groups of four for 30 minutes, thus allowing them to discuss and propose different options. After this time, each group presented its results in class.

Finally, and to determine their opinion of the activity, each PST completed a questionnaire in which they were asked to evaluate the activity itself (from 0 to 5), the difficulty in designing it and in implementing it (from 1 to 5, with 1 being not difficult and 5 very difficult), their initial opinion of the teaching possibilities of the activity and the possibility of using it with secondary students (from 1 to 5, with 1 being very limited possibilities and 5 significant possibilities), indicate the best and worst aspects when performing the activity, and explain how they expected secondary students to receive the activity if put into practice.

RESULTS

PSTs' proposals

The students' proposals were based on two characteristics, namely hair type and hair colour. With respect to hair type, they initially attempted to find an explanation based on two alleles (S for straight hair and C for curly hair), with one being predominant, but found that this could not explain the three phenotypes (straight, spiky and curly). To that end, the PSTs established an intermediate inheritance relationship between allele S and C, fitting this to all the crosses shown in Figure 1.

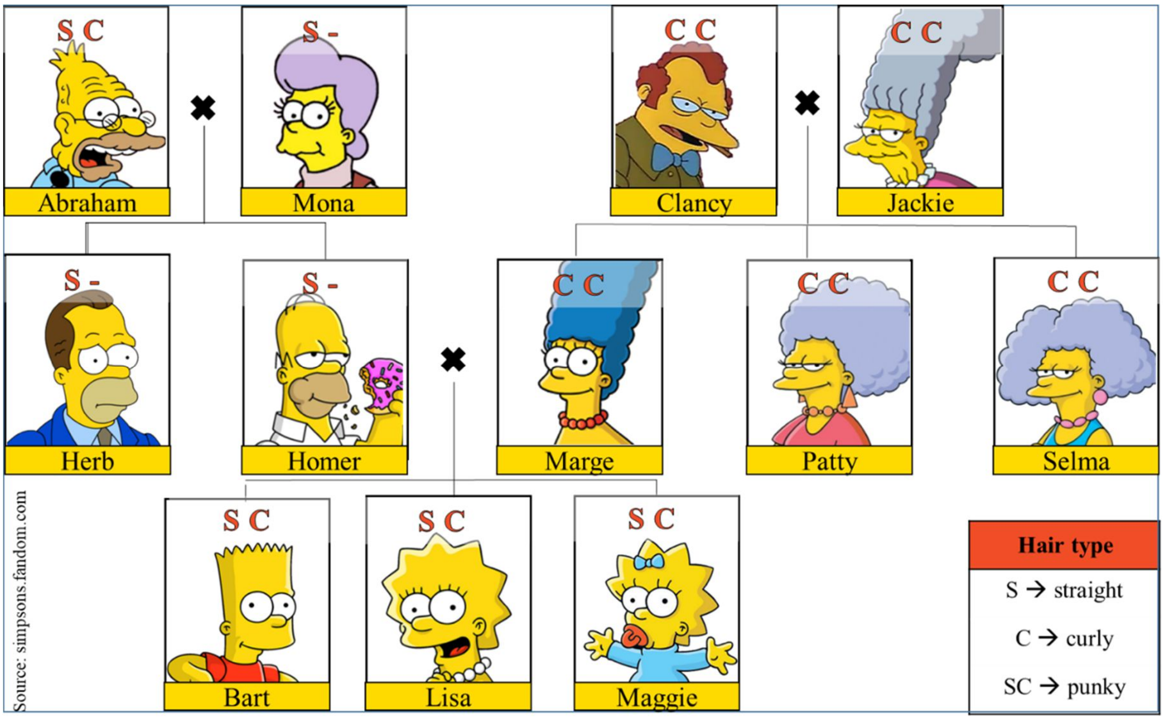

Figure 1. Genotypes and crosses for hair type in the Simpsons family [Source: simsons.fandom.com].

In this way, homozygous individuals (SS) will exhibit straight hair, heterozygous individuals (SC) will exhibit punky hair, and homozygous individuals (CC) will exhibit curly hair. Consequently, it is not possible to know all genotypes (for instance, Mona, Herb or Homer, like you can see in Figure 1).

A similar procedure was followed for hair colour, with the PSTs attempting to propose an intermediate inheritance with alleles *B* for blue hair and *M* for brown hair, although this could not explain and cross between Abraham and Mona and between Clancy and Jackie using a single criterion, as can be seen from Figure 2.

As such, they proposed a possible solution based on an autosomal recessive inheritance for blue hair (*b* for blue and *B* for a colour other than blue). The *B* allele is dominant and the *b* allele is recessive. The phenotypes brown and yellow hair colour cannot be explained with this proposal, thus meaning that other factors must be involved.

Thus, homozygous individuals (BB) and heterozygous individuals (Bb) will exhibit a hair colour that is not blue (for instance, Abraham, Clancy, Herb, Homer, Bart, Lisa or Maggie); and homozygous individuals (bb) will exhibit blue hair (like Mona, Jackie, Marge, Patty or Selma). For this reason, it is not possible to know all genotypes (for example, Abraham or Clancy). Finally, they concluded that, according the Mendel's third law, transmission of these characteristics is independent, in other words they are not linked.

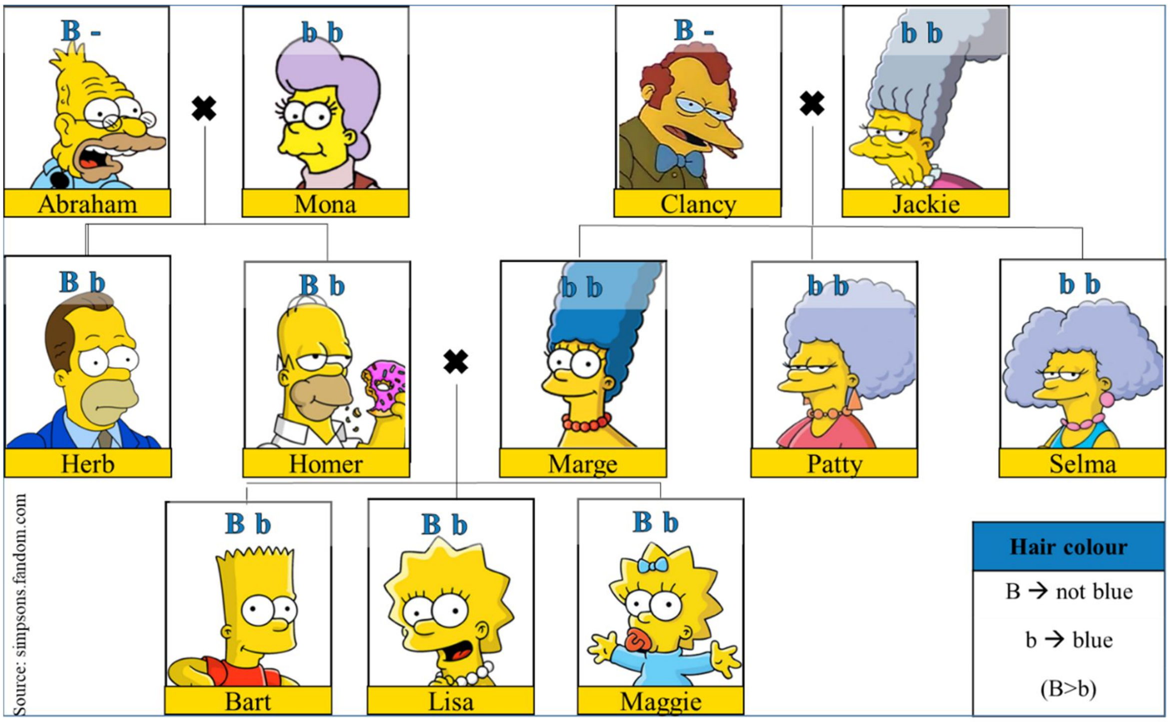

Figure 2. Genotypes and crosses for hair colour in the Simpsons family [Source: simsons.fandom.com].

PSTs' Assessments

The PSTs evaluated the activity very favourably, giving a score of 4.25/5. On a five-point scale, they gave the highest scores to the possibility of using this resource in the secondary classroom (4.0) and the possibility of putting it into practice (4.0). Conversely, they considered it to be difficult to implement (2.67) and to design (3.1) (Figure 3).

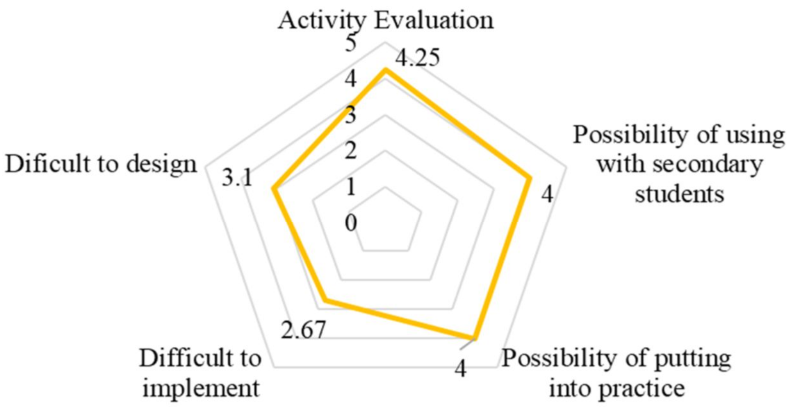

Figure 3. PSTs' activity evaluation.

The majority of the PSTs also considered the "versatility" of the activity to be its best aspect as it can be adapted to numerous series and films and that it was a "fun and motivational activity". The aspects given the worst evaluations were the "complexity of the content", "finding a genotypical response that can explain the phenotypical diversity in the series", or "performing the activity in cooperative groups and online".

As regards how they would expect secondary students to receive the activity if put into practice, the majority responses concentrated on creating interest, enthusiasm and ebullience, amongst students.

CLOSING REMARKS

The effects of integrating films, series, TV programmes, stories or novels in science education can be investigated by designing similar studies in an extended way for different levels of formal education (Hamalosmanoglu, Kizilay & Saylan Kirmizigül, 2020), from kindergarden to secondary education or including the university stage. As noted by Raham (2004) or Perales and Vilches (2005), despite the obstacles that may arise in class, this type of activity is effective for teaching science to secondary students.

This proposal attempted to prepare PSTs for task design and to create an innovative vision in them. In addition, as with previous studies (Franco-Mariscal, 2021), although the use of adult TV series with PSTs does not imply their use in secondary education, it nevertheless allows students taking the Teaching Masters to learn about this type of resource and become aware of the need to adapt series to the age and interests of their future students.

Research conducted with cartoons showed that the students displayed a significant enhancement in their motivation towards science learning and academic achievement. Moreover, they increased students' active participation in the classroom, enabling and enhancing conceptual understanding, and creating environments for cognitive conflict and debate (Evrekly, Inel & Balim, 2011).

Another example is Dalacosta, Kamariotaki-Paparrigopoulou, Palyvos and Spyrellis' research (2009). The research results provide evidence that the use of cartoons significantly increases the young students' knowledge and understanding of science concepts, which are normally difficult to comprehend and often cause misconceptions to them.

The PSTs also highlighted the difficulty of finding a biological explanation for all characteristics as some were impossible to explain with the laws of Mendelian genetics. This may be due to the fact that these aspects were not taken into consideration when creating the cartoons because cartoonists would have not a deep knowledge of genetics. Other options may be that characters are not the same age (when people are older, they have gray hair) or a biological explanation, such as Abraham or Clancy were not the biological fathers.

According to the results obtained, this resource, which is easy to design and implement, is suitable for the teaching-learning of the inheritance of secondary characteristics. The resource studied may be extended to other TV families (The Flintstones, The Incredibles or Harry Potter), for which other characteristics, such as eye colour, intelligence, build, obesity or visual problems, could be studied.

ACKNOWLEDGEMENTS

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REFERENCES

AIMC, Asociación para la investigación de medios de comunicación (2018). Resumen general 2018. Madrid: AIMC.

Barnett, M., & Kafka, A. (2007). Using Science Fiction Movie Scenes to Support Critical Analysis of Science. *Journal of College Science Teaching*, *36*(4).

Dalacosta, K., Kamariotaki-Paparrigopoulou, M., Palyvos, J.A., & Spyrellis, N. (2009). Multimedia application with animated cartoons for teaching science in elementary education. Computers & Education, 52(4), 741-748.

Evrekly, E., Inel, D., & Balim, A. G. (2011). Research on the effects of using concept cartoons and mind maps in science education. Necatibey Eğitim Fakültesi Elektronik Fen ve Matematik Eğitimi Dergisi, 5(2), 58-85.

Fraknoi, A. (2002). Teaching astronomy with science fiction: a resource guide. *Astronomy Education Review*, *1*(2), 112-119.

Franco-Mariscal, A. J. (2021). Enseñar física con juego de tronos. Estudio del movimiento. *Revista Mexicana de Física E*, *18*(1), 63-68.

Franco-Mariscal, A.J., Cano-Iglesias, M.J. & Hierrezuelo, J.M. (2020). Game of Thrones to Learn Science: An Experience with Spanish Pre-Service Science Teachers. In O. Levrini & G. Tasquier (Eds.), *The Beauty and Pleasure of Understanding: Engaging with Contemporary Challenges Through Science Education (Proceedings of ESERA 2019),* (pp. 545-556). Bologna: Alma Mater Studiorum, University of Bologna.

Hamalosmanoglu, M., Kizilay, E., & Saylan Kirmizigül, A. (2020). The Effects of Using Animated Films in the Environmental Education Course on Prospective Teachers' Behavior towards Environmental Problems and Their Attitude towards Solid Waste and Recycling. *International Online Journal of Education and Teaching*, *7*(3), 1178-1187.

Hasse, C. (2015). The material co-construction of hard science fiction and physics. *Cultural Studies of Science Education*, *10*(4), 921-940.

Kilby-Goodwin, K. (2010). Putting the" Science" in" Science Fiction". *The Science Teacher*, *77*(5), 60.

Koutnikova, M. (2017). The application of comics in science education. *Acta Educationis Generalis, 7*(3), 88-98.

López-Fernández, M.M & Franco-Mariscal, A.J. (2019). Students' Perceptions about the *GeneticsHome* educational game at the High School Level. *Revista Eletrônica Ludus Scientiae, 3*(2), 1-11.

Orthia, L. A., Dobos, A. R., Guy, T., Kan, S. Z., Keys, S. E., Nekvapil, S., & Ngu, D. H. Y. (2012). How Do People Think About the Science They Encounter in Fiction? Undergraduates Investigate Responses to Science in The Simpsons. *International Journal of Science Education*, Part B, 2(2), 149–174.

Perales, F.J. & Vílchez, J.M. (2005). The teaching of physics and cartoons: Can they be interrelated in secondary education? *International Journal Science Education*, *27*(14), 1647-1670.

Rose, C. (2003). How to teach biology using the movie science of cloning people, resurrecting the dead, and combining flies and humans. *Public Understanding of Science*, *12*(3), 289-296.

HOW SEPARATING EVERYDAY AND SCIENTIFIC LANGUAGE IN CHEMISTRY TEACHING ENHANCES LEARNERS' COMMUNICATIVE COMPETENCES

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The pursuit of Scientific Literacy as a response to questions of educational inequality has become much more complex, especially in countries, which have faced immigration and growing diversity in recent years. STEM education should therefore pay additional attention to students' diverse backgrounds, for instance regarding their language resources. Integrated language instruction or language-sensitive teaching are among various approaches to meet this requirement, however, there still seems to be a lack of initiative from the individual subject areas.

The Disaggregate-Instruction-Approach (DIA, Brown et al., 2010) addresses the issue by offering learners new ways to access scientific discourse. Brown and colleagues report that learners with beginner and developing verbal skills benefit greatly from the strict separation of subject-content and language learning. This approach reduces the cognitive load through allowing students to focus first on familiar language in the process of acquiring scientific concepts and introduces scientific vocabulary in a subsequent stage. Picking up the very promising findings from previous studies, we adapted the approach to the conditions in a culturally as well as linguistically highly diverse area and conducted an intervention study with first- and second-year chemistry learners to gather data on how they benefit from a modified DIA. The focus of this paper centers the initial results of the analysis of students' subject-specific learning gains as effects of the treatment.

Keywords: Language in Science Education, Disaggregate Instruction

INTRODUCTION

In times of rapidly increasing diversity – particularly in a growing number of European societies largely affected by immigration – stakeholders in science education are more than ever required to pay special attention to students who face specific challenges in their individual learning biographies (OECD, 2019, pp. 181–183). The make-up of this diverse group contains a substantial number of learners who are second language learners. In Germany, a country that has experienced constantly high numbers of immigrants and refugees during past years, between 34 and 40 percent of the student population are first- or second-generation immigrants (Autorengruppe Bildungsberichterstattung, 2020, p. 27) who to a substantial degree speak a language other than German in their homes (Becker-Mrotzek et al., 2012, p. 2). Recent large-scale assessment like the international PISA or TIMSS surveys identified substantial differences in reading performance (OECD, 2019, p. 185) and STEM learning (Mullis et al., 2020, p. 294; Wendt et al., 2020, p. 298) between immigrant and non-immigrant students in several European countries. Among a variety of supposed factors, researchers consider the family's and student's socio-economic status as well as an imbalance between the languages spoken at home and in school the primary reasons for this alarming gap in reading but also in the sciences (OECD, 2019, p. 185; Wendt et al., 2020, pp. 306–307). Scholars have discussed the interrelatedness of language competences, like reading or writing, and science competences and found evidence that under-developed verbal competences have a substantially negative impact on learning in STEM subjects (Bird & Welford, 1995, pp. 396–397; Childs et al., 2015, p. 421). Therefore, the analysis of students' deficits in academic language proficiency and the question to what extent these deficits impede competence development in STEM education should focus on the entire student population, i.e., second language learners as well as students with low socio-economic status.

THEORETICAL FRAMEWORK

In German education research there has been broad consensus regarding the theory that integrated language instruction (referred to as "Durchgängige Sprachbildung" in German) as a component of every school subject can help the majority of students to overcome their language deficits (Gogolin & Lange, 2011, p. 118). Consequently, it seems plausible and necessary to develop approaches to the integration of language instruction into science teaching from the perspective of the individual subjects and to evaluate the effects of these approaches. Under the assumption that the acquisition of scientific vocabulary in some respects resembles the acquisition of a foreign language (Rincke, 2011, pp. 255–256; Vygotsky, 2012, p. 109), focusing instruction on subject-specific, conceptual understanding and novel items of scientific vocabulary at the same time should result in a significant cognitive load on students' working memory (Roussel et al., 2017, p. 78). While humans have evolved to acquire their native language, the acquisition of foreign languages usually fulfills cultural purposes and thus our brains need to apply different cognitive processes (Roussel et al., 2017, p. 72; Sweller, 2015, p. 190). Geary theorizes this distinction with the concept of biologically primary and secondary knowledge which demand differentially extensive efforts from learners to be acquired (Geary, 2008). The cognitive load when dealing with two types of biologically secondary knowledge, e.g. a foreign language and scientific knowledge, is higher as we need explicit instruction and dedication to succeed (Roussel et al., 2017, p. 73).

Different studies have shown that the challenges for learners in science subjects are particularly high because of the simultaneous focus on scientific concepts and vocabulary, i.e. two types of biologically secondary knowledge, due to a high cognitive load (Brown et al., 2010, pp. 1479-1480; Brown et al., 2019, p. 766). Research in multilingual settings in the United States revealed that the acquisition of scientific concepts induced improved learning efficiency as well as an enhanced articulation of the acquired knowledge for students if the instruction mainly used everyday terminology initially (Brown et al., 2010; McDonnell et al., 2016). Using this idea, Brown et al. (2010) and Ryoo (2015) designed a series of science lessons in the field of photosynthesis and empirically analyzed the effects of the so-called *Disaggregate-Instruction-Approach (DIA)*. According to their approach, the introduction of scientific terms should only happen after the students have internalized the corresponding scientific concepts (Brown et al., 2010; Ryoo, 2015).

Brown and colleagues used the idea of *Disaggregate Instruction* to design a teaching sequence which they call Directed Discourse Approach to Science Instruction (DDASI). It subdivides a given sequence into four phases (2010, pp. 1474-1475):

(1)Pre-Assessment Instruction

(2)Content Construction

(3)Introduction of Explicit Language

(4)Scaffolding Opportunities for Language

After familiarizing the students with the new topic and students' preconceptions (1), the teacher introduces new content which the learners negotiate only using everyday language (2). Afterwards the teacher presents the new scientific terminology (3) and eventually provides the students with activities to apply the acquired vocabulary (4).

RESEARCH QUESTION

Our ideas to adapt the promising *DIA* to meet the conditions of a diverse student population in a multilingual, urban setting led us to the following overarching research question:

To what extent does the separation of teaching sequences into initial phases in which the teacher primarily uses familiar language and only later introduces new scientific terms (in accordance with the DIA) assist students in the acquisition of chemistry-related knowledge and the development of chemistry-specific communicative competences?

RESEARCH METHOD AND STUDY DESIGN

Instead of merely replicating Brown and colleagues' study, we have made several adaptations to the proposed instructional design with the aim to complement their research in the field of chemistry education in the German educational system. For example, Brown and colleagues did not examine their participants' language abilities and based their categorization solely on the individual's cultural and language-learning background instead (2010, p. 1473). In contrast, we decided to conduct an analysis of students' general and scientific language abilities as we expect specific effects of the approach, especially for learners with developable communicative competences. Furthermore we faced the challenge to establish a border between the concepts of everyday and scientific vocabulary which we intend to meet with the help of Brown and Spang who draw parallels to vernacular and nonvernacular language (2008, pp. 710–711). We believe that terms and the corresponding concepts that the students are already familiar with (like water molecule or state of matter; SenBJF, 2015) should be considered vernacular as the chemistry class as a community knows how to use these terms properly even though they might seem nonvernacular (or scientific) to people outside of this community (Brown & Spang, 2008, p. 710). Hence, nonvernacular or scientific terms are only those terms which are completely new to the students (here: all the words that describe the subatomic structure of salts and the dissolving process). In contrast to Brown et al. (2010, p. 1475) we decided to refrain from virtual teaching and opted for an authentic in-person classroom setting. Even though this added the teacher as a possibly confounding variable, we are convinced that we can mitigate the effect if the teacher stays the same person for every group.

We designed a sequence of four 90-minute units aimed at early-stage, secondary-level chemistry learners with the adapted *Disaggregate Instruction* teaching approach (Brown et al., 2010) serving as the treatment. To evaluate its effectiveness, we use a treatment-control study design with pre- and post-test measures. The treatment and control groups receive instruction of the same content using identical teaching methods. The treatment group studies the scientific concepts initially only using familiar language and acquires the scientific terminology afterwards. The control group does not experience a strict separation of content- and language-learning, i.e., the teacher introduces a new scientific term and the corresponding concept simultaneously.

In the pre-test and thus prior to the instruction, every student takes two c-tests measuring their general (Institut für Bildungsmonitoring und Qualitätsentwicklung Hamburg, 2008) and scientific (test developed and sampled by ourselves) language abilities. C-tests are a test type closely related to cloze tests[5] but here only the first or second half of a word is erased and needs to be completed. According to their scores, the students can be classified regarding their verbal skills. This will be considered in the statistical analysis but does not affect the assignment to treatment or control group.

Before and after the treatment the students also complete a subject-matter knowledge test in a multiple-choice-single-select format (Gieske, 2021) to detect knowledge gains as effects of the instructional approach. The test consists of 14 items; each item contains 3 distractors apart from the correct answer. In addition, the participants have to indicate how confident they feel answering each item on a four-level Likert scale (Erb & Bolte, 2012, pp. 16–17). Hence, each student receives two separate scores representing their learning gains: the *performance score* purely reflects the selection of correct answers whereas the *performance & confidence score* also takes into account the confidence in answering and thus reduces the probability of assessing answers which the participant only guessed correctly.

The treatment itself, as outlined in figure 1, covers the topics chemical structure of salts as well as the dissolving process of salts in water. It incorporates student-centered, collaborative activities as well as a variation of media. The teaching sequence is embedded in the context "The Dead Sea is Dying" which as a socio-scientific issue creates a learning environment that is both interesting and challenging for the students (Sadler, 2009, p. 36). The scientific vocabulary of this teaching sequence consists of ten items which we mainly drew from the local

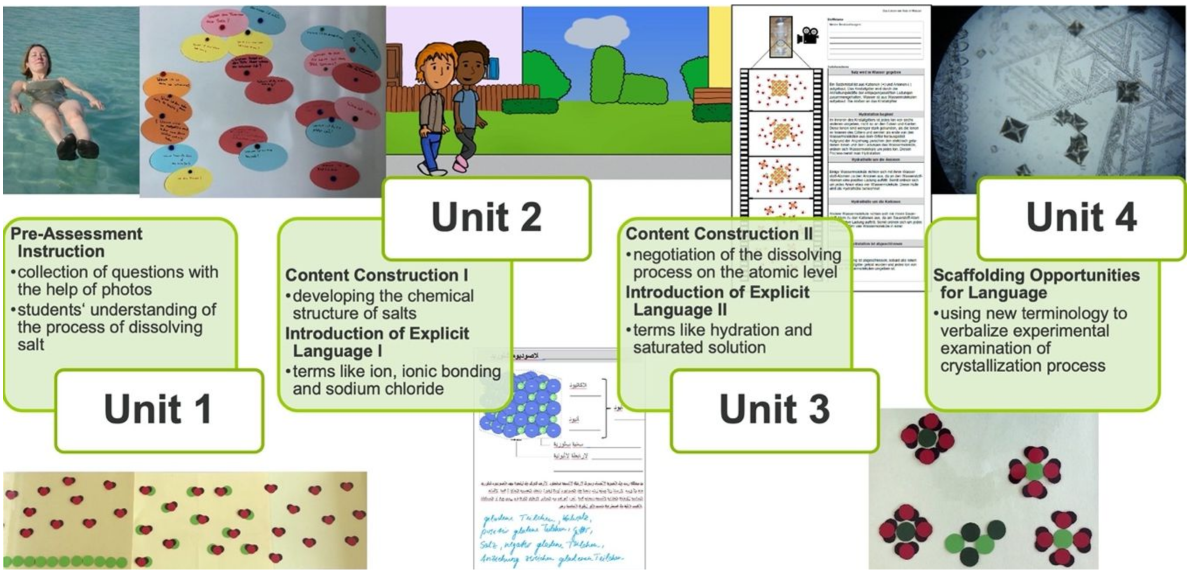

Figure 1. Overview of the teaching sequence including teaching material and student products.

[5] Oller & Jonz define cloze tests as „written applications … [in which] single words are replaced with blanks of standard length and the respondent tries to fill in each blank" (1994, p. 3).

chemistry curriculum (SenBJF, 2015, p. 36) and supplemented with some linguistically directly related terms, e.g. ion, cation and anion.

The four phases of the DDASI approach are not identical with the four units of "The Dead Sea is Dying" but they are woven into the sequence. The first unit serves as the Pre-Assessment Instruction. Here the teacher makes the students familiar with the context as well as the topic and invites the class to pose questions which the learners would like to discuss throughout the sequence. During the second half of the first unit the students work with applications to depict their pre-instructional ideas of the dissolving process (bottom left corner in figure 1) which gives the teacher the opportunity to monitor students' language use and prior knowledge. In the second unit the teacher introduces the chemical structure of salts and the concept of ionic bonding with the help of two fictional characters who remember a visit to a museum at the Dead Sea during their holidays. As they do not have all details and terminology in mind, their conversation serves as the vantage point to discuss the subatomic structure of salts without dense scientific vocabulary (Content Construction I). A scientist helps the characters to understand the scientific concept of ionic bonding and to become aware of the different purposes of colloquial and scientific language (Introduction of Explicit Language I). The third unit then brings together the conceptual findings and introduces the process of dissolving a salt in water (Content Construction II). Here we use a movie bar worksheet where students have to arrange the correct order of visualizations and textual elements (Introduction of Explicit Language II). Afterwards the students use and consolidate their knowledge and depict a saturated solution with salt-ion and water-molecule applications (bottom right corner in figure 1). The fourth phase and final unit provides the learners with meaningful opportunities to demonstrate their understanding applying the new terminology during a hands-on activity and scaffolded teacher-student interaction.

After the teaching sequence, the participants attend to two items measuring their ability to communicate in a manner that addresses the text recipient. In this test they write two texts addressing an expert (their chemistry teacher) and a novice (a peer who did not participate in the teaching sequence) explaining the dissolving of salt in water. We are currently developing an analytical framework to map chemistry-specific ways which students use to establish audience design in their writing. This framework helps us to investigate the role of the newly acquired scientific terminology in students' writing and text construction processes.

STUDY SAMPLE AND INITIAL FINDINGS

Pilot Study

First investigations with four groups took place at two different schools with diverging conditions concerning student attainment in May and June of 2021. We tested our teaching sequence at a so-called academic high school and a regular high school with lower student attainment in general. The two classes at each school were randomly assigned to treatment (TG) or control group (CG).

The allocation of 102 subject-matter knowledge tests (pre and post) revealed a satisfactory reliability of Cronbach's α = .802. A substantive drop-out due to COVID-19 prevention measures reduced the sample to only 36 students who completed both, the pre- and the post-test. Table 1 shows selected statistical characteristics for the *performance (perf)* and the *performance & confidence scores (perf & conf;* cf. Research Method and Study Design*)* of the treatment and control groups from both schools.

Table 1. Descriptive statistics of the pilot study treatment and control groups.

Group	Treatment (N = 18)		Control (N = 18)	
Score	***perf***	***perf & conf***	***perf***	***perf & conf***
Mean score t_0	3.83	1.17	5.06	1.56
Standard Deviation t_0	1.38	0.92	2.56	1.46
Mean score t_n	8.78	6.44	9.56	7.56
Standard Deviation t_n	2.32	2.46	2.01	3.17
Mean score Δt_n-t_0	4.94	5.28	4.50	6.00
Standard Deviation Δt_n-t_0	2.80	2.16	2.33	2.72

The results reveal a substantive gap between the *performance* and the *performance & confidence scores* for the pre-test in both groups. In the post-test this gap still exists but has become smaller in relation to the generally improved scores. There is a tendency of the treatment group to slightly outperform the control group when the *performance scores* are taken into account *($M_{TG} = 4.94$; $M_{CG} = 4.50$)*. The control group, however, exhibits a greater learning gain compared to the treatment group when *performance & confidence scores* are considered *($M_{CG} = 6.00$; $M_{TG} = 5.28$)*. Yet, this difference does not become statistically significant *($p = .384$)*.

Main Study

The main study started after the summer break of 2021 with four groups at two different academic high schools. These two schools are located in fairly privileged areas of Berlin and their educational attainment can be considered substantively higher compared to the pilot study groups. One class at each school was assigned randomly to the treatment and the other to the control group. Table 2 shows descriptive statistics for both groups.

Table 2. Descriptive statistics of the main study treatment and control groups.

Group	Treatment (N = 48)		Control (N = 47)	
Score	***perf***	***perf & conf***	***perf***	***perf & conf***
Mean score t_0	5.69	1.83	5.51	2.21
Standard Deviation t_0	1.99	1.59	2.19	1.84
Mean score t_n	10.94	9.88	10.70	9.55
Standard Deviation t_n	1.69	2.28	1.69	2.38
Mean score Δt_n-t_0	5.25	8.04	5.19	7.36
Standard Deviation Δt_n-t_0	2.23	2.51	2.38	2.40

The initial results of the main study show a similar trend regarding the students' confidence when completing the test compared to the pilot study. The pre-test scores are much higher for both groups when only performance is considered. In the post-test the *performance* and *performance & confidence scores* are more similar. This time the treatment group achieved a greater learning gain compared to the control group when we consider the *performance & confidence scores* ($M_{TG} = 8.04$; $M_{CG} = 7.36$). However, this trend does still not become significant in a two-tier t-test ($p = .180$). Regarding the performance scores, the difference between both groups is only marginal ($M_{TG} = 5.25$; $M_{CG} = 5.19$).

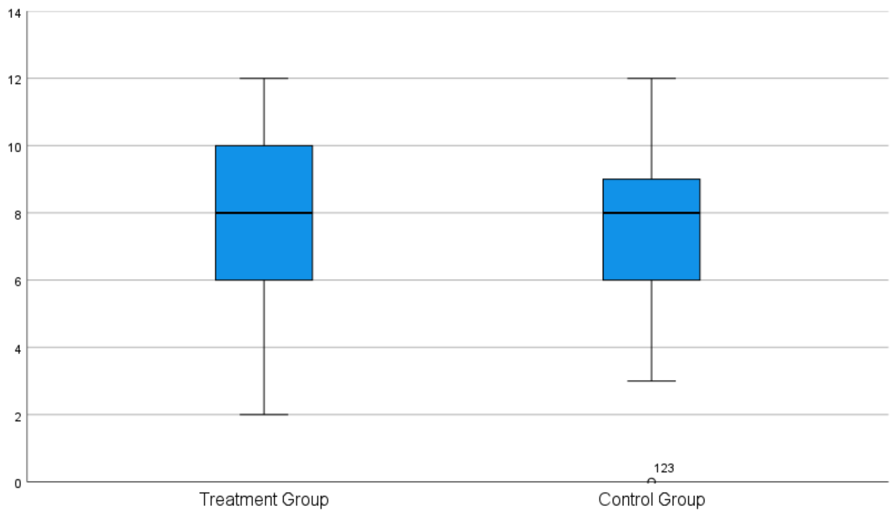

Figure 2. Boxplots of knowledge test *perf & conf score* gains from pre- to post-test.

DISCUSSION OF FINDINGS AND OUTLOOK

The pilot study in June and May 2021 was constrained by the pandemic situation and consequently exhibited a significant drop-out of participating students. Nevertheless, the data reveal important implications for our main study. The very satisfactory reliability of the subject-matter knowledge test confirms the appropriateness for measuring students' learning gains throughout the teaching sequence. The pre-test scores are similarly low in both groups as the students only bring marginal prior knowledge to the classroom, however, the teaching – independent from the type of treatment – leads to substantially improved results afterwards. In order to eliminate the chance of guessing the correct answer, the *performance & confidence score* turned out to be a helpful measure as the students systematically scored below the level of probability in the pre-test when their confidence was considered. The teachers' and students' informal feedback on the teaching sequence turned out very positive and encouraging which is another reason why we only had to carry out minor modifications prior to the main study.

Our findings from the investigations of the first four main study groups confirm the suitability of the subject-matter knowledge test and our focus on the *performance & confidence scores*. The mean pre-test scores are slightly higher but as anticipated still on a low level but ($M_{TG} = 1.83$, $M_{CG} = 2.21$). One main parameter that provides evidence for the effectiveness of the teaching approach is the mean learning gain score. The treatment group outperforms the control group by a margin of $\Delta = 0.78$ ($M_{TG} = 8.04$, $M_{CG} = 7.36$). This means that students who received *Disaggregate Instruction* answer on average 8 more items correctly in the post-test than they did before the teaching sequence – compared to a bit more than 7 items in the control group. Even though this tendency does not become statistically significant, we think it indicates an imaginably superior effectiveness of the *Disaggregate-Instruction-Approach* in relation to high-quality chemistry teaching without a strict separation of content- and language-learning.

The sample size in both, pilot and main study, however, places some limitations on our conclusions. Our objective is to expand the data set to solidify statistical effects paying particular attention to groups from less privileged backgrounds as we assume that students who already perform very well at school potentially do not struggle a lot with the simultaneous acquisition of scientific concepts and terminology. Consequently, we will primarily include classes from regular high schools in the course of our main study as we expect lower-attaining students to benefit substantially and even to a higher degree from the disaggregation and the reduced cognitive load. We suspect that the amplification of the sample will likely help to find robust statistical evidence for the effectiveness of the *Disaggregate Instruction-Approach*.

In addition, the classification of the students regarding their c-test results as well as the analysis of student text samples addressed at two different people with varying prior knowledge will certainly help to complement our initial findings and further pursue our research question. By adding more data and new insights to the findings from previous studies on *Disaggregate Instruction* we hope to contribute to the global linking of research on language instruction in science teaching and, most of all, to support students who struggle with the diverse demands of science learning.

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REFERENCES

Autorengruppe Bildungsberichterstattung. (2020). *Bildung in Deutschland 2020 [Education in Germany in 2020]*. wbv Media.

Becker-Mrotzek, M., Hentschel, B., Hippmann, K., & Linnemann, M. (2012). *Sprachförderung in deutschen Schulen—Die Sicht der Lehrerinnen und Lehrer. Ergebnisse einer Umfrage unter Lehrerinnen und Lehrern [Language support in German schools—The teachers' perspective. Results of a teacher survey]*. Mercator-Institut.

Bird, E., & Welford, G. (1995). The effect of language on the performance of second-language students in science examinations. *International Journal of Science Education*, *17*(3), 389–397.

Brown, B. A., Donovan, B., & Wild, A. (2019). Language and cognitive interference: How using complex scientific language limits cognitive performance. *Science Education*, *103*(4), 750–769.

Brown, B. A., Ryoo, K., & Rodriguez, J. (2010). Pathway Towards Fluency: Using 'disaggregate instruction' to promote science literacy. *International Journal of Science Education*, *32*(11), 1465–1493.

Brown, B. A., & Spang, E. (2008). Double talk: Synthesizing everyday and science language in the classroom. *Science Education*, *92*(4), 708–732.

Childs, P. E., Markic, S., & Ryan, M. C. (2015). The Role of Language in the Teaching and Learning of Chemistry. In J. García-Martínez & E. Serrano-Torregrosa (Eds.), *Chemistry Education: Best Practices, Opportunities and Trends* (First, pp. 421–446). Wiley-VCH.

Erb, M., & Bolte, C. (2012). Kompetenzen von Grundschulkindern der Jahrgangsstufen 5/6 im Bereich "Naturwissenschaftliches Arbeiten" [Primary school students' competences in science learning in grades 5 and 6]. *GDSU-Journal*, 11–22.

Geary, D. C. (2008). An Evolutionarily Informed Education Science. *Educational Psychologist*, *43*(4), 179–195.

Gieske, R. (2021). Fachwissenstest ‚Aufbau und Lösevorgang von Salzen in Wasser', unveröffentlicht [Subject-matter knowledge test "Subatomic structure and the dissolving process of salts in water", unpublished].

Gogolin, I., & Lange, I. (2011). Bildungssprache und Durchgängige Sprachbildung [Language of schooling and integrated language instruction]. In S. Fürstenau & M. Gomolla (Eds.), *Migration und schulischer Wandel: Mehrsprachigkeit [Migration and educational change: Multilingualism]* (pp. 107–127). VS.

Institut für Bildungsmonitoring und Qualitätsentwicklung Hamburg. (2008). *C-Test Klasse 7/8 "Überfall +3" [C-test for grades 7 and 8 "Theft +3"].*

McDonnell, L., Barker, M. K., & Wieman, C. (2016). Concepts first, jargon second improves student articulation of understanding. *Biochemistry and Molecular Biology Education*, *44*(1), 12–19.

Mullis, I. V. S., Martin, M. O., Foy, P., Kelly, D. L., & Fishbein, B. (2020). *TIMSS 2019 International Results in Mathematics and Science*. TIMSS & PIRLS International Study Center, Lynch School of Education, Boston College.

OECD. (2019). *PISA 2018 Results (Volume II): Where All Students Can Succeed*. OECD.

Rincke, K. (2011). It's Rather like Learning a Language: Development of talk and conceptual understanding in mechanics lessons. *International Journal of Science Education*, *33*(2), 229–258.

Roussel, S., Joulia, D., Tricot, A., & Sweller, J. (2017). Learning subject content through a foreign language should not ignore human cognitive architecture: A cognitive load theory approach. *Learning and Instruction*, *52*, 69–79.

Ryoo, K. (2015). Teaching Science Through the Language of Students in Technology-Enhanced Instruction. *Journal of Science Education and Technology*, *24*(1), 29–42.

Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education*, *45*(1), 1–42.

Senatsverwaltung für Bildung, Jugend und Familie Berlin. (2015). *Rahmenlehrplan für die Jahrgangsstufen 7-10. Chemie [Framework curriculum for grades 7 to 10. Chemistry]*.

Sweller, J. (2015). In Academe, What Is Learned, and How Is It Learned? *Current Directions in Psychological Science*, *24*(3), 190–194.

Vygotsky, L. S. (2012). *Thought and language* (E. Hanfmann, G. Vakar, & A. Kozulin, Eds.; Rev. and expanded ed). MIT Press.

Wendt, H., Schwippert, K., Stubbe, T. C., & Jusufi, D. (2020). Mathematische und naturwissenschaftliche Kompetenzen von Schülerinnen und Schülern mit und ohne Migrationshintergrund [Mathematics and science competences of students' with and without a migration biography]. In K. Schwippert, D. Kasper, O. Köller, N. McElvany, C. Selter, M. Steffensky, & H. Wendt (Eds.), *TIMSS 2019. Mathematische und naturwissenschaftliche Kompetenzen von Grundschulkindern in Deutschland im internationalen Vergleich [TIMSS 2019. Primary school students' mathematics and science competences compared* (pp. 291–314). Waxmann.

IN-SERVICE TEACHERS' ADAPTATION OF CONTEMPORARY RESEARCH TOPICS TEACHING MODULES UNDER MENTORING SUPPORT

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The negotiation of cutting-edge research topics in science lessons may contribute to students' scientific literacy. Even though respective teaching modules have been developed, their dissemination requires appropriate preparation and support for teachers to meet the challenges of such a venture. In this context, this study examines adaptations in-service teachers make to modules on cutting-edge research topics with the support of their mentors. In total 5 mentors and 32 in-service teachers participated in the study. The adapted modules and transcripts of the mentoring meetings were analysed. Data indicate that both teachers and mentors contributed to the adaptations, which were mostly focused on the activities of the teaching modules and that teachers' initiatives for adaptions were related to their mentor's guiding style.

Keywords: Teaching Innovations, Teaching Learning Sequences, Mentoring in Teacher Education

INTRODUCTION

Integrating teaching modules related to cutting-edge research in science classes familiarizes students with the process of scientific research and provides them with the opportunity to experience scientific knowledge as an ongoing procedure and to elaborate on its social implications (Wong et al., 2008). However, such an endeavour has not yet been broadly incorporated in science curricula and therefore it is still considered as an innovative practice for teachers. We consider as an educational innovation any new idea, teaching approach or practice which is novel for a specific target group and concerns an intentional activity that aims at changing an existing practice (Rogers, 2003). One of the means used to inform the practice of in-service teachers and to operationalize and disseminate educational innovations is the implementation of innovative teaching modules (Pintó et al., 2014) as they comprise a powerful learning experience for teachers, who are introduced to new educational approaches.

However, the dissemination of innovative teaching materials from the original context to the multiple implementation contexts is an inherently transformative process to the extent that teachers evaluate, adapt and finally implement the respective teaching module, in the light of their own personal teaching style, their students' needs and the particularities of their classroom (Pintó et al., 2005). To represent that interpretive process, Brown & Edelson (2003) introduced a framework that emphasizes the active role played in this participatory relationship by both the teachers (who bring in their personal resources) and the teaching material with its particular characteristics. The result of this interaction that takes place between the teacher and the teaching material falls into a range that extends between exact adoption of teaching material, its adaptation and the improvisation of the teacher. Thus, an innovation, in order to be disseminated and sustained, must embrace the active, interpretive teachers' role and their need to develop ownership of the innovation (Melville, 2008).

Hence, the introduction of an innovative teaching module should be appropriately supported during its implementation in order teachers to cope with the problems that arise in their daily teaching practice (Bitan-Friedlander et al., 2004). In particular, this ongoing support can be most effective when provided within a learning community, by a more experienced colleague acting as mentor and as a scaffold to support teachers in acquiring ownership of the innovation (Rogan, 2007). In our study we adopted the approach of mentoring in collaborative settings as it involves teachers in active learning processes by implementing teaching innovations, collaboratively exploring ways to improve their day-to-day practice and reflecting on it (Bradbury, 2009; Feiman-Nemser, 2012).

Based on this approach, the aim of the present study is to give an insight on the adaptations in-service teachers make to modules on cutting-edge research topics with the support of their mentors within learning communities. The main research question is: *How do in-service mentee-teachers adapt modules on cutting-edge research topics in order to implement them in their classrooms with the support of their mentors?* and it is examined through the following sub-questions:

(i) What adaptations do mentee-teachers and mentors propose?
(ii) What kind of practices do mentors use in order to support their mentors while adapting the modules?

METHOD

Research Design

In the context of our research, 5 mentors (who were previously trained in nanotechnology education and had developed and piloted a nanotechnology module) supported 32 primary and secondary education teachers in groups of 6-7 persons, in implementing a module on a cutting-edge research topic. The selected topics were: Nanotechnology applications, Microplastics in the ocean and Carbohydrates of baby formulas. All three modules were developed in the framework of the EU-project IRRESISTIBLE (www.irresistible-project.eu). Their innovative elements resided on:

- the negotiation of current research topics,
- the introduction of Responsible Research and Innovation (RRI) framework from educational standpoint in order to negotiate social implications of science (Owen et al., 2012),
- inquiry-based approach to learning, a process in which students are actively engaged by scientifically oriented questions, develop evidence-based knowledge of scientific phenomena and get acquainted with scientific practices (Minner et al., 2010) and
- the development of interactive scientific exhibits by the students as a means of communicating their newly acquired knowledge with their classmates and the public.

The mentoring process lasted for about 9 months during which each group held about 8 mentoring meetings and was divided in three successive phases. In the orientation phase, mentors and mentees elaborated on the scientific content of each module, the involved social implications and aspects of inquiry-based learning. In the redesign phase, mentees thoroughly examined the modules and then re-designed them in order to adapt them to each school context.

The implementation phase concerned the enactment of the modules in real class conditions and the mentees' reflection on the mentoring experience.

Data collection and analysis

Our main data source was the adapted teaching materials that were produced by the teachers and the audio-recordings of all the group mentoring meetings.

Due to the explorative nature of the research, qualitative methods of content analysis were used. Teachers' adaptations in all three teaching modules were identified through the detailed examination of the final lesson plans and teaching materials and their comparison with the original material they had received. As adaptation we defined any variation from the original teaching module, which was implemented by the teachers, whether it was originally suggested by a mentor or a teacher of the learning communities. These adaptations were categorized as related to (i) the scientific content of the modules, (ii) the activities carried out by students or teachers in the classroom and (iii) the materials which students interacted with (Table 1). Moreover, through the examination of the transcripts of the meetings we distinguished the adaptations as originally proposed by a mentor or by one of the teachers.

Table 1. Coding scheme for teachers' adaptations.

Categories	Criteria
Subject matter	Addition of related concepts
	Omission of concepts
Activities	Addition of activities
	Modification of activities
	Omission of activities
Physical Materials	Use of different materials
	Modification or development of new worksheets
	Use of different digital materials

Regarding mentors' style, the mentoring practices that emerged from the data were organized into two broad categories, according to Crasborn et al. (2011). Mentoring practices who tended to bring in information (e.g., sharing ideas and suggestions, giving feedback, giving instructions) were categorized as directive. In contrast, mentors' practices that aimed to extract information from the teachers (e.g., asking questions, reflecting, encouraging the development of alternatives) were categorized as non-directive.

RESULTS

Data analysis revealed that the majority of the adaptations were focused on the activities of the teaching modules, followed by the adaptations regarding the materials, while the number of those concerning the scientific content of the modules was more limited (Figure 1). This trend was common throughout all three teaching modules. However, noteworthy differences were observed in the number of adaptations suggested by teachers compared to those suggested by mentors in each teaching module. In the Nanotechnology module, teachers and mentors contributed equally to its adaptation, even if mentors' suggestions were mainly focused on the module's activities while the teachers proposed and carried out more practical modifications regarding materials of these activities. On the other hand, in the Microplastics and the Milk carbohydrates module we observed that mentors' suggestions for adaptations were far more limited than the teachers' across all the categories (content, activities and materials).

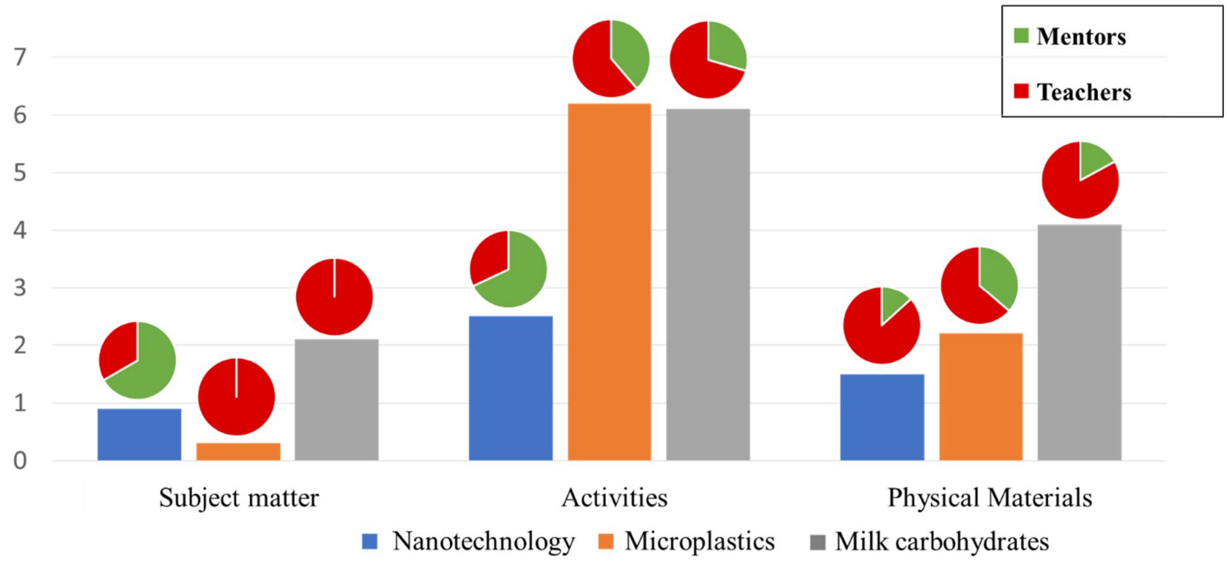

Figure 1. Absolute frequency of adaptations per teaching module and person that introduced them.

The results among the three modules were also similar in case of the practices mentors employed to support their mentee-teachers. Across all five learning communities mentors tended to use mostly directive practices in order to guide the teachers throughout the re-design phase, as sharing their opinion and experience from previous implementation of the Nanotechnology module and explaining the significance of the incorporated innovative elements. However, they adopted a far more directive mentoring style when supporting the implementation of the Nanotechnology module than the Microplastics and the Milk carbohydrates module.

Table 2. Percentage of use of mentoring practices.

Mentoring Practices		Nanotechnology	Microplastics	Milk carbohydrates
Directive practices	Model	32%	11%	9%
	Advise	29%	27%	34%
	Give feedback	17%	20%	28%
	Evaluate	7%	11%	7%
Non-directive practices	Posing questions	5%	13%	9%
	Encourage	8%	12%	10%
	Summarise	2%	6%	3%

In fact, our results revealed a negative correlation between the adoption of a more directive mentoring style and the suggestion of adaptations by the teachers themselves for all three modules (Figure 2). This means that the less directional the mentors were, the more initiatives teachers took to suggest modifications of the modules.

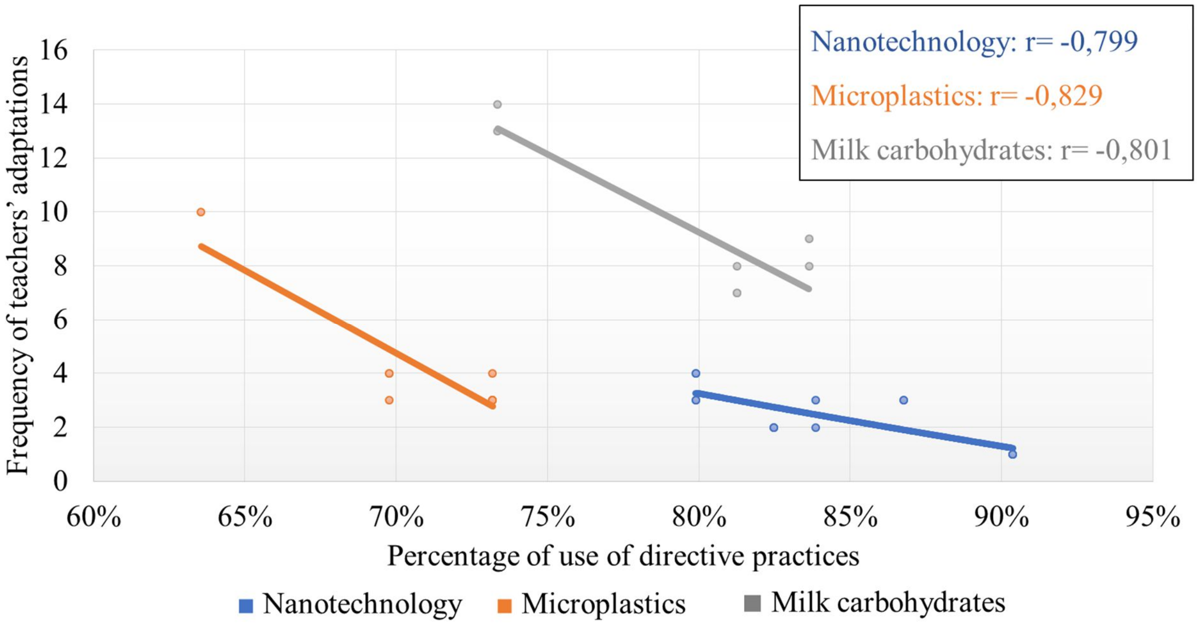

Figure 2. Correlation between mentors' use of directive practices and the absolute frequency of teacher-introduced modifications.

DISCUSSION AND CONCLUSIONS

In the context of our study, the participating teachers were invited to apply in their classrooms ready-made innovative teaching modules on cutting-edge research topics. However, as highlighted by Brown (2009), the preparation of their lessons had a strong redesigning orientation, through which teachers developed ownership of the innovation adapting the modules to their teaching style, their students' needs and school context. The above took place in a safe environment shaped by the non-evaluative guidance provided by mentors, and in collaboration with colleagues who had a common goal. In this process, the mentors did not just have a supportive role, but actively participated by proposing themselves and supporting a significant number of modifications based on their previous experience. Moreover, mentors' contribution in this process was crucial as it was their intervention that ensured that the adapted modules would remain faithful to the spirit of the innovation, despite the requisite teachers' modifications. Finally, the results on the correlation between the mentoring style and the development of the teachers' sense of ownership may also contribute to the formation of guidelines regarding the support that should be provided to teachers in order to implement an innovation, emphasizing the balance between freedom to adapt innovations and guidance to ensure that these adaptations do not alter the rationale of the innovation. All the above elements reinforce the position that group mentoring is not only a useful tool for teachers' professional development but may also be used to support the implementation of innovative teaching modules.

Given that teacher modifications are intertwined with the degree of ownership and their importance in the sustainability of the innovation the results on the correlation between the mentoring style and the development of the teachers' sense of ownership may also contribute to the formation of guidelines regarding the support that should be provided to teachers in order to implement an innovation, emphasizing at first the ongoing support throughout the implementation phase and secondly the balance between freedom to adapt innovations and guidance to ensure that these adaptations do not alter the rationale of the innovation. Therefore, the active participation of in-service teachers in the process of both developing and disseminating a TLS is considered beneficial and as such it must be evaluated by science education research.

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REFERENCES

Bitan-Friedlander, N., Dreyfus, A., & Milgrom, Z. (2004). Types of "teachers in training": the reactions of primary school science teachers when confronted with the task of implementing an innovation. *Teaching and Teacher Education, 20*(6), 607–619.

Bradbury, L. (2009). Educative mentoring: Promoting reform-based science teaching through mentoring relationships. *Science Education, 94*(6), 1049-1071.

Brown M., (2009). The Teacher–Tool Relationship: Theorizing the Design and Use of Curriculum Materials. In J. Remillard, B. Herbel-Eisenman, & G. Lloyd (Eds.), *Mathematics teachers at work: Connecting curriculum materials and classroom instruction* (pp. 17–37), Routledge.

Brown, M. W., & Edelson, D. (2003). *Teaching as design: Can we better understand the ways in which teachers use materials so we can better design materials to support their changes in practice?* Evanston: Center for Learning & Technology in Urban Schools, Northwestern University.

Crasborn, F., Hennissen, P., Brouwer, N., Korthagen, F., & Bergen, T. (2011). Exploring a two-dimensional model of mentor teacher roles in mentoring dialogues. *Teaching and Teacher education*, *27*(2), 320-331.

Feiman-Nemser, S. (2012). Beyond solo teaching. *Educational Leadership, 69*, 10–16.

Melville, W. (2008). Mandated curriculum change and a science department: A superficial language convergence? *Teaching and Teacher Education, 24*(5), 1185–1199.

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—what is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching, 47*(4), 474-496.

Owen, R., Macnaghten, P., & Stilgoe, J. (2012). Responsible research and innovation: From science in society to science for society, with society. *Science and public policy, 39*(6), 751-760.

Pintó R., Hernández M. and Constantinou C., (2014). On the transfer of teaching-learning materials from one educational setting to another. In Bruguière C., Tiberghien A, and Clément P. (Eds.), *Topics and Trends in Current Science Education* (pp. 535–552). Springer.

Pintó, R., Couso, D., & Gutierrez, R. (2005). Using research on teachers' transformations of innovations to inform teacher education. The case of energy degradation. *Science education, 89*(1), 38-55.

Rogan, J. M. (2007). How much curriculum change is appropriate? Defining a zone of feasible innovation. *Science Education, 91*(3), 439-460.

Rogers, E. M. (2003). *Diffusion of innovations* (5th ed.). New York, NY: Free Press

van Driel, J. H., Verloop, N., & de Vos, W. (1998). Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching, 35*(6), 673–695.

Wong, S. L., Hodson, D., Kwan, J., & Yung, B. H. W. (2008). Turning Crisis into Opportunity: Enhancing student-teachers' understanding of nature of science and scientific inquiry through a case study of the scientific research in severe acute respiratory syndrome. *International Journal of Science Education, 30*(11), 1417-1439.

EVOLUTION OF THE MODELS OF MILK FERMENTATION OF SECONDARY STUDENTS IN THE DEVELOPMENT OF A TEACHING LEARNING SEQUENCE ON THE NEED TO TAKE YOGURT

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Modeling is a scientific practice that allows students to learn, describe and predict scientific phenomena through representations, images, models, etc. However, modeling is a complex process that requires the acquisition of several scientific skills. As students acquire skills to work with models, they develop not only scientific skills, but also social, linguistic, etc. This study presents the evolution of the models on the transformation of milk into yogurt (lactic fermentation) by 23 10th grade students from two schools in the province of Malaga (Spain) at different times of a teaching-learning sequence (TLS), focused on the preparation of yogurt and if this is a healthy food. In order to analyze the models proposed by the students, a simplified school model was used, consists of three phases (1. reproduction of bacteria, 2. acid formation and 3. protein denaturation), finding 5 categories depending on the phases that could be identify in their answers. The evolution of the models was studied over 4 moments: before the TLS, after knowing the composition of milk and yogurt, after making homemade yogurt, and at the end of the TLS after knowing the scientific model. The results showed that the student models are getting closer to the reference school model as the TLS progresses, detailing all the phases in the last two moments and decreasing the frequency of students who do not indicate any model. However, there is not a significant number of students who include the three phases in the model, so work must continue in this regard.

Keywords: Models in Science, Secondary School, Teaching Learning Sequence

INTRODUCTION

The teaching of the chemical reaction model in the context of fermentation, poses a challenge to the most common approaches in the initiation to the learning of chemistry, in which the chemical reaction models are raised from simple phenomena of the inorganic world (Aragón, Oliva & Navarrete, 2010). We consider that, although it can be teaching from a more complex way and requires a careful educational transposition (Chevallard, 1998), the importance that the model can have in explaining everyday phenomena is gained. The importance of food in daily life, both personally and socially, makes this context relevant for the chemistry teaching at the secondary school. Specifically, kitchen chemistry is considered a very useful context in science education given the large number of chemical and physical concepts that can be addressed in it, the ease in preparing some recipes, and the similarity of the kitchen with a science lab. For this reason, this study uses yogurt as a context to study the evolution of Spanish grade 10 students' models on the transformation of milk into yogurt (lactic fermentation) at different times of a teaching-learning sequence (TLS) that addresses this topic.

METHOD

The study is carried out in a TLS focused on the production of yogurt and if this may or may not be considered a healthy food (Muñoz, Franco and Blanco, 2020) implemented with 23 10th grade students from two secondary schools in Malaga (Spain) (A and B) in the field of chemistry. The age of the participants was 16 years and 52% were girls. The TLS was developed in 9 one-hour class sessions in which different tasks related to modeling were interspersed. To identify the student models, a simplified school model involving three phases was used. Phase 1, reproduction of bacteria, consists of an increase in the number of bacteria in the milk as the temperature increases through a biological mechanism. In the second phase, a chemical transformation occurs where milk sugar (lactose) is divided into glucose and galactose, transforming glucose into lactic acid by the action of bacterias. In phase 3 the transformation is completed by intervening the lactic acid obtained as a product in the previous phase. This phase consists of the denaturation of proteins by the action of lactic acid through a chemical transformation, producing a decrease in pH (Muñoz, Franco and Blanco, 2020).

In order to know the evolution of the lactic fermentation models proposed by the students, four moments of the TLS were analyzed in which they were asked to explain this transformation with a model and a drawing: (1) before the TLS, (2) after to know the composition of milk and yogurt, (3) after making homemade yogurt, and (4) at the end of the TLS, after knowing the scientific model. At moments 1 and 2, the students were helped by indicating that bacteria were responsible for the transformation of milk sugar into acid (phase 2), while in moment 3, the help consisted in indicating that the components involved they were bacteria, sugars and milk (phases 1, 2 and 3). Moment 4 differs from the others in that it requires an open explanation of the process. The aim is to analyze the evolution of the student models with the same type of questions and less help.

The transformation of milk into yogurt is from the ontological point of view (Chi et al., 1994) a concept related to a process and for an adequate explanation of it, it is necessary to attend to the following aspects: What material things are involved? (systems), what happens between them? (type of interaction), and what things change during the process? (type of transformation). In a previous paper (Franco-Mariscal, Blanco-López and España-Ramos, 2018) this scheme was used to analyze the models of the students on another process such as dental caries, in which the models were categorized around in two dimensions, the active agent and the mechanism. And based on these two dimensions, a progress scheme of the models identified in the students was proposed. The application of this scheme to the transformation of milk into yogurt involves identifying the entities (milk and bacteria), the interaction that occurs between them and those that result (yogurt).

For this, a reading of the answers was carried out, and through an inductive and iterative process the different categories emerged. In order to categorize the answers, the drawings and explanations offered by the students were analyzed jointly in each of the tasks about models during the different moments of the TLS, from which the possible underlying models could be identified. In this study, it is considered that a mental model on the transformation of milk into yogurt must have the three phases mentioned above and in each of them indicate two components (the agent and the mechanism).

Of the answers given by the students, it has been possible to identify five categories: (C1) no model, (C2) models that explain the transformation including only phase 1, (C3) models including only phase 2, (C4) models including phases 1 and 2, and (C5) models including phases 2 and 3.

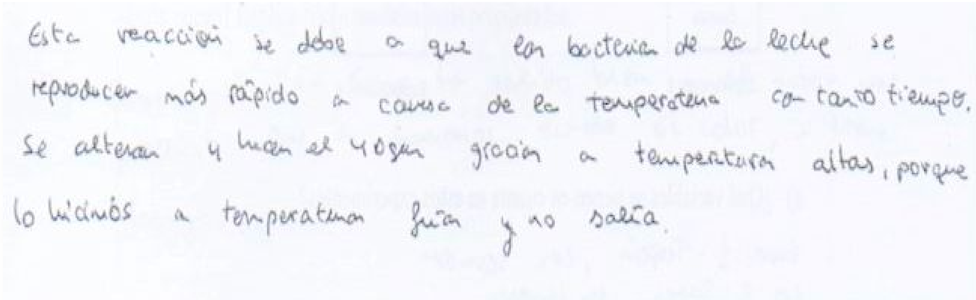
RESULTS

Analysis by phases of the scientific school model

Phase 1. Increase in the number of bacteria

First, it is necessary to point out that very few students mention this phase of the process and all of them are from group B. Furthermore, these models only appear when the students have prepared homemade yogurt.

A model has been identified that considers that during this phase a biological transformation takes place that consists of the reproduction of bacteria. This model indicates that the agent is the bacteria and as a mechanism the reproduction of the bacteria itself with the help of temperature, as we can see in figure 1.


Esta reacción se debe a que las bacterias de la leche se reproducen más rápido a causa de la temperatura con tanto tiempo. Se alteran y hacen el yogur gracias a temperaturas altas, porque lo hicimos a temperatura fría y no salía.

Translation: “This reaction is due to the fact that the bacteria in the milk reproduce faster by high temperature. They get excited and make the yogurt, because it was made at a low temperature and the milk did not turn into yogurt”

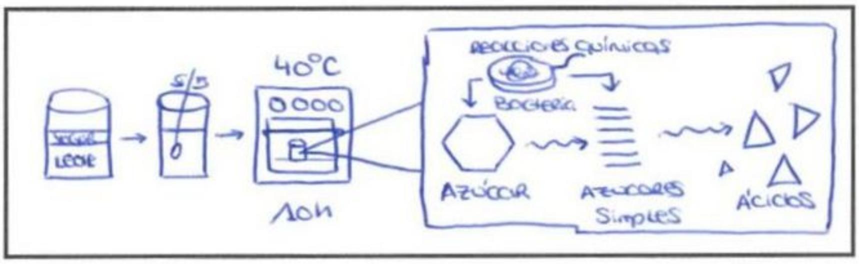
Figure 1. Biological transformation (Phase 1).

The fact that this model is only found in one of the groups shows that it is not an aspect that students can achieve on their own through the experience of making yogurt. It may be due to the knowledge that certain students had about the reproduction of bacteria and the factors that accelerate it. These results show the need to devote specific attention to this phase of the process, addressing specifically to students the role that temperature plays in the transformation of milk into yogurt.

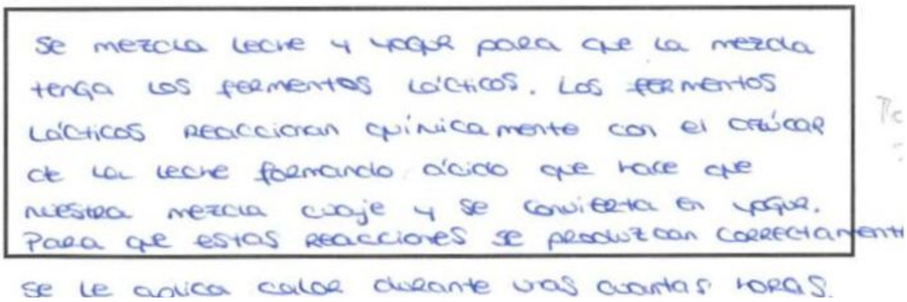
Phase 2. Transformation of sugar into acid

In this phase, the students' answers are more complex to analyze since they include references to the four elements of the model (agent, support, product and mechanism). A large number of models appear when different agents are combined with mechanisms being mentioned by both groups.

The most frequent model is the closest to the reference school model, indicating that by the action of bacteria, milk is transformed into yogurt through a chemical transformation (figure 2).



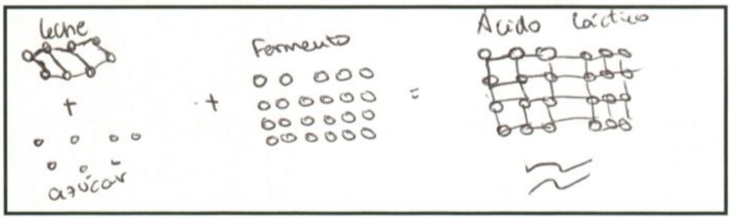
b) Explicación.



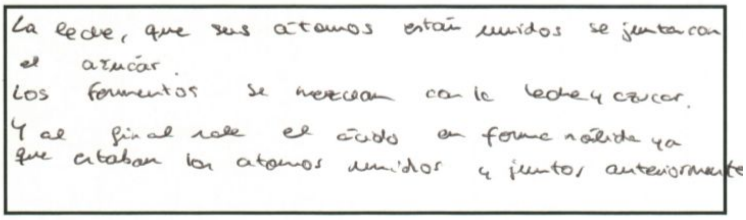
Translation: "Milk is mixed with yogurt so that the mixture has the lactic ferments. These chemically react with the sugar in the milk to form acid, which causes the mixture to curdle and turn into yogurt. For the reaction to take place, high temperature is necessary for a period of time**".**

Figure 2. Chemical transformation whose agent is bacteria (Phase 2).

Considering the agent, in all the moments of the TLS, the one that is most mentioned is that of "bacteria" followed by "bacteria and other components". Almost all the answers of the students that mention "bacteria and other components" as an agent indicate that the process goes through a physical transformation (figure 3).



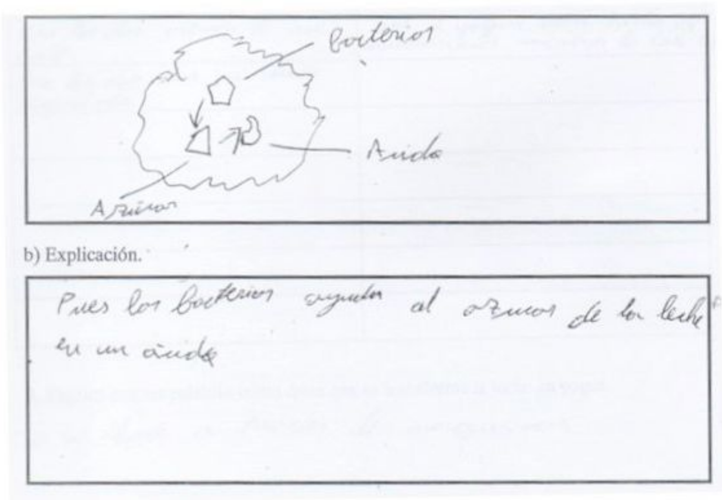
b) Explicación.



Translation: "The lactic ferment mixes with the atoms of the milk, in such a way that the atoms come together and form the yogurt".

Figure 3. Physical transformation whose agent is bacteria (Phase 2).

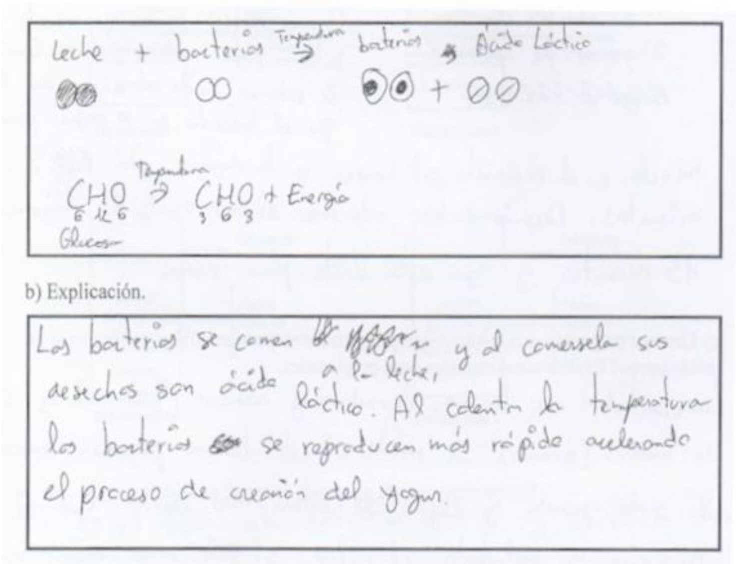
From the point of view of the mechanisms, the chemical transformation is the one that the vast majority of students' answers. Only three students do not indicate the type of mechanism that the process of transforming milk into yogurt undergoes and these answers are given before starting with the teaching sequence (figure 4).



Translation: "Bacteria convert milk sugar into acid".

Figure 4. Does not specify transformation, bacteria agent (Phase 2).

This phase is the only one where the mechanism related to biological functions appears (figure 5), in which the students mention that the transformation process takes place through the digestion of the bacteria considered as an agent.

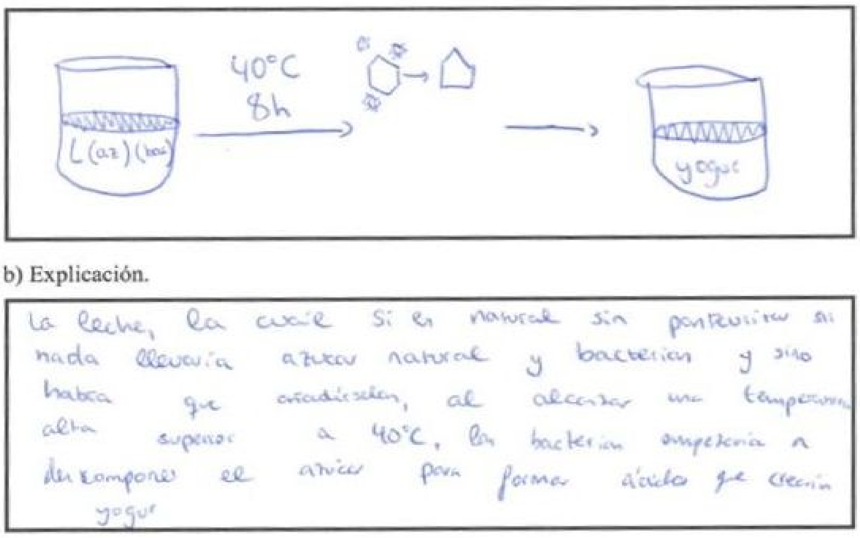


Translation: "Bacteria eat sugar and their waste is converted into lactic acid. As the temperatura increases, bacteria reproduce faster, accelerating the reaction".

Figure 5. Biological transformation whose agent is bacteria (Phase 2)

Phase 3. Protein denaturation

Contrary to what happened in phase I, this phase is only mentioned by students from group A. To categorize the answers to some model of this phase, it has been taken into account as a criterion that there were explicit indications or references to a transformation subsequent to the second phase. The frequent model is the closest to the reference school model, indicating that a chemical transformation occurs through an agent that is acid (figure 6).



Translation: “Milk carries sugar and bacteria, at a temperatura above 40ºC, bacteria begin to break down the sugar in the milk to transform i tinto acid”.

Figure 6. Chemical transformation whose agent is acid (Phase 3).

Analysis by moments of the TLS

Before TLS (moment 1). Categories C1 (minority), C3 and C5 were detected (Figure 7).

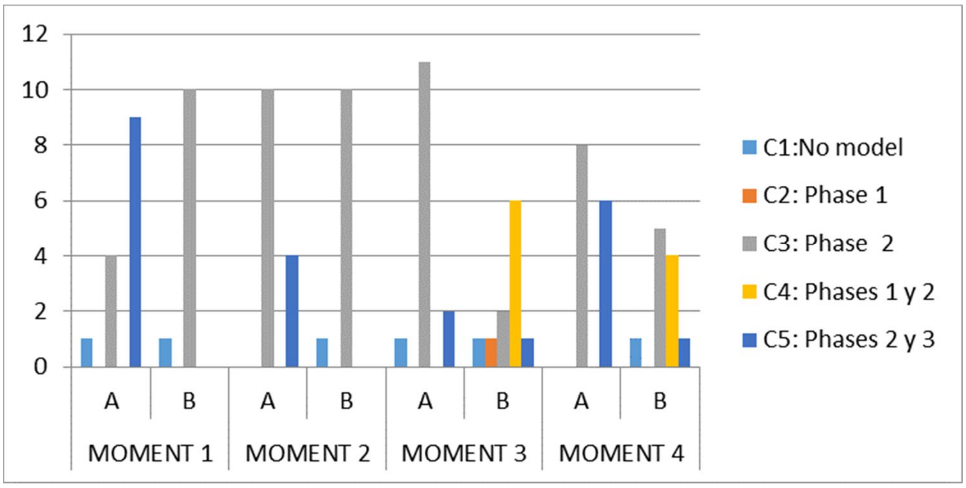


Figure 7. Overall results of both groups at the different moments of the TLS.

While in group B the responses were only related to phase 2 (C3), some students in group A relied on phases 2 and 3 (C5), this type of response being the majority in this group**.**

After knowing the composition of milk and yogurt (moment 2). Same categories were found as at moment 1, with the majority response being C3 (phase 2 only), cited equally in both groups. A student without a model (C1) was found in group B. Only in group A were responses that referred to both phase 2 and 3 (C5) detected. Attending to moment 1, the number of students in group A that indicated phase 2 increased, while in group B it remained.

After making homemade yogurt (moment 3). The five categories were found, with C3 being the majority category, as in the previous moments. Only in group B explanations were detected that included phase 1 (C2), or phases 1 and 2 (C4), the latter being the majority response. However, in group A, the most numerous response continued to be that indicated only in phase 2 (C3). Comparing these results with those obtained at other times, in group B there are fewer students who mention phase 2 (C3), increasing this category in group A.

At the end of the TLS, after knowing the scientific model (moment 4). Four categories were found (C1, C3, C4 and C5) being again the majority C3. Students in group A only mention either phase 2 (C3) or phases 2 and 3 (C5) exclusively. With respect to previous moments, in this group there was an increase in the frequency of students who considered that the process is carried out through two phases (categories C4 and C5) and not just one. However, there is still a significant number of students who consider a single phase. On the other hand, the student who did not indicate a model, disappeared. In group B, they again mentioned C3, C4 and C5, the answer that states that the process is only carried out through phase 1 (C2) disappears and the student continues who does not recognize any pattern (C1). Also decrease the number of students indicated by C4 by increasing the answers for C3. In both group A and B, the majority category is C3.

CONCLUSIONS

The results show an important progress in the lactic fermentation models expressed by the students when advancing in the TLS, finding all the phases of the school model in the last two moments and decreasing the frequency of students who do not indicate any model. It seems that making yogurt in the classroom and knowledge of the scientific model are important to better understand how transformation occurs. The results also show, that the TLS achieves that a good number of students are able to explain lactic fermentation with more advanced models than those usually found in the literature (Moreno & López, 2013). However, not all students have been able to include all three phases at the moment, so more modeling tasks must continue in the classroom to achieve this goal. Finally, the differences found between the two groups regarding the mentioned phases, may be due to the initial background of these students in understanding the chemical reaction or the role of bacteria in biochemical reactions, a topic that will be the object of study in future research.

ACKNOWLEDGMENTS

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REFERENCES

Aragón, M.M., Oliva, J.M. & Navarrete, A. (2013). Evolución de los modelos explicativos de los alumnos en torno al cambio químico a través de una propuesta didáctica con analogías [Development of explanatory models of students about chemical change through a methodological approach with analogies]. *Enseñanza de las Ciencias, 31*(2), 9-30.

Chevallard, Y. (1998). La transposición didáctica. [The didactic transposition]. Aique.

Chi M., Slotta J. & Leeuw, N. (1994) From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction*, 4, 27-43.

Franco-Mariscal, A.J.; Blanco-López, A. y España-Ramos, E. (2018). Identifying and improving students' mental models of tooth decay. Finlayson, O.; McLoughlin, E.; Erduran, S. & Childs,

P. (General editors). *Research, Practice and Collaboration in Science Education* (Proceedings of ESERA 2017). pp. 118 - 127

Moreno, G. & López, A. (2013). Construcción de modelos en clase acerca del fenómeno de la fermentación con alumnos de educación secundaria [Fermentation phenomenon classroom model construction with secondary school students]. *Revista Latinoamericana de Estudios Educativos (Colombia)*, *9*(1), 53-78.

Muñoz-Campos, V., Franco-Mariscal, A.J & Blanco-López, A. (2020). Integration of scientific practices into daily living contexts: a framework for the design of teaching-learning sequences. *International Journal of Science Education*, *42*(15), 2574-2600. DOI: 10.1080/09500693.2020.1821932.

DEVELOPMENT OF PROCEDURAL KNOWLEDGE AND EXPERIMENTATION SKILLS IN SECONDARY EDUCATION

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This study examines the development of procedural knowledge and experimentation skills in high-school students after a context-specific Teaching Learning Sequence (TLS) in a virtual AC electric circuit laboratory environment. The students (N=18, aged 16-17) were subjected to an inquiry-based teaching intervention aiming at developing their procedural knowledge, experiment design and implementation skills. A TLS was developed and enriched with explicit teaching of the experimentation procedures and inclusion of metacognition-enhancing activities. A pre-/post-instructional assessment scheme was used to evaluate students' procedural knowledge and experimentation skills. Our data comprise completed questionnaires for assessing procedural knowledge and worksheets completed during pre- and post-task in-class assignments for assessing experimentation skills. Overall, after instruction, students have significantly advanced their procedural knowledge and experimentation skills on the subject of AC electric circuits. The statistical analysis of our data shows a strong correlation between the procedural knowledge (completed questionnaires) and the experimentation skills (worksheet task assignments) acquired by the students.

Keywords: Teaching Learning Sequences, Inquiry-based teaching, Scientific Experimentation

INTRODUCTION

Studies suggest that inquiry-based teaching using virtual laboratory environments can promote students' engagement in experimental investigative activities thus enhancing their conceptual understanding of physical phenomena (Ruten et al., 2012). Furthermore, being involved in such activities, students may also acquire investigative skills, such as hypothesis forming, variable identification, experimental procedure description and implementation, results evaluation and conclusion drawing (Taramopoulos et al., 2011). The acquisition of such skills by students is an important ingredient towards the understanding of scientific methodologies of experimentation. However, the development of students' experimentation skills alone does not suffice for them to design and implement scientifically valid experiments, since experiment design and implementation are relevant to both the scientific domain being studied, and the scientific methodology (Garratt & Tomlinson, 2001). And there is evidence that students find it difficult to set up and perform well-designed experiments (de Jong & van Joolingen, 1998). Hence the term 'practices' has been suggested to be used instead of the term skills to emphasize the requirement for both knowledge on aspects of experimentation and skills in scientific experimentation (NCR, 2013).

Inquiry-based teaching using either physical (PL) or virtual (VL) laboratory environments can promote students' engagement in laboratory activities and help them acquire experimentation skills (Brinson, 2015), through teaching of the implemented experimental procedures either implicitly (Lefkos et al. 2011), or explicitly (Vorholzer et. al., 2020). Explicit teaching is deemed to be quite efficient for secondary school students in domains like mechanics or DC electricity by the recent study of Vorholzer et. al. (2020) who report that by including explicit teaching of the inquiry phases as part of the instruction and combining this with metacognition-enhancing activities, students' skills and knowledge may be further improved. It seems then plausible that one way to develop students' experimentation skills would be to teach them explicitly scientific procedures of experimentation embedded in normal domain inquiry-based instruction. It is expected that by such explicit teaching students may develop both their understanding of the physical phenomena under study (cognitive knowledge) and their understanding of scientific procedures followed when designing and contacting scientifically valid experiments (procedural knowledge), while developing their experimentation skills through investigative activities. Therefore, it is important that further evidence is provided on the efficiency of such an approach and that the relation between the development of students' procedural knowledge and their experimentation skills is further investigated.

Although research in Teaching Learning Sequence (TLS) is a productive area of research, most TLS studies have focused on examining students' enhancement of domain knowledge rather than on the development of their procedural knowledge or investigative skills. In this context we have developed and applied an innovative inquiry-based technology-enhanced TLS, integrating VL in the area of AC circuits for secondary school students and taking into account TLS design issues suggested in the literature (Psillos & Kariotoglou 2016), aiming at enhancing both students' procedural knowledge and experimentation skills. Our present research aims at examining whether the development of procedural knowledge, being offered explicitly during such an enriched inquiry-based TLS to secondary education students, correlates well with the development of students' experimentation skills in terms of designing and performing scientific experiments in a virtual AC circuit laboratory environment.

METHOD

Participants were 18 students (17-18 yrs) from a senior high school in Greece. All students had some prior knowledge of DC electric circuits, but none of them had received any prior instruction on AC circuits. Our approach drew on teaching the scientific procedures of experimentation explicitly, involving students in inquiry-based guided experimental activities utilizing an open virtual laboratory environment in AC circuits. The virtual laboratory environment used was the open virtual electric circuit laboratory WebLab of the Science Center and Technology Museum (NOESIS), equipped with a user-friendly drag-and-drop interface and an affordance of dynamically-linked concrete and abstract representations of electric circuits, shown in figure 1 (Molohidis et al., 2015).

The TLS consisted of seven hourly units with modular worksheets. The activity worksheets contained an initial problem-question and students were prompted to design an appropriate experiment to solve the problem, construct a suitable circuit and carry out the experimental procedure they had designed. Thus they prompted students to provide answers for various aspects of experimentation, including formation of a hypothesis, proposal of experimental verification of the hypothesis, identification of variables affecting the phenomena being studied, listing of devices and instruments needed, describing the experimental setup, the phenomena taking place and the experimental process, setting up the appropriate circuit for the experiment, taking and analyzing measurements, evaluating and interpreting results, drawing conclusions and evaluating the initial hypothesis.

Students were randomly divided into six subgroups of two and two subgroups of three, while each subgroup had access to a single computer. They were first directed to discuss the questions of the worksheets within their subgroup and if their problems were not solved, they were asked to initiate an open discussion with the whole class. During this open class discussion, subgroups were expected to refer to their views and findings on the issue raised and converge to the scientific answer through the supervision and coordination of the instructor. The instructor also filled in any missing field knowledge so that the students have an understanding of the phenomena taking place in the circuits they were studying.

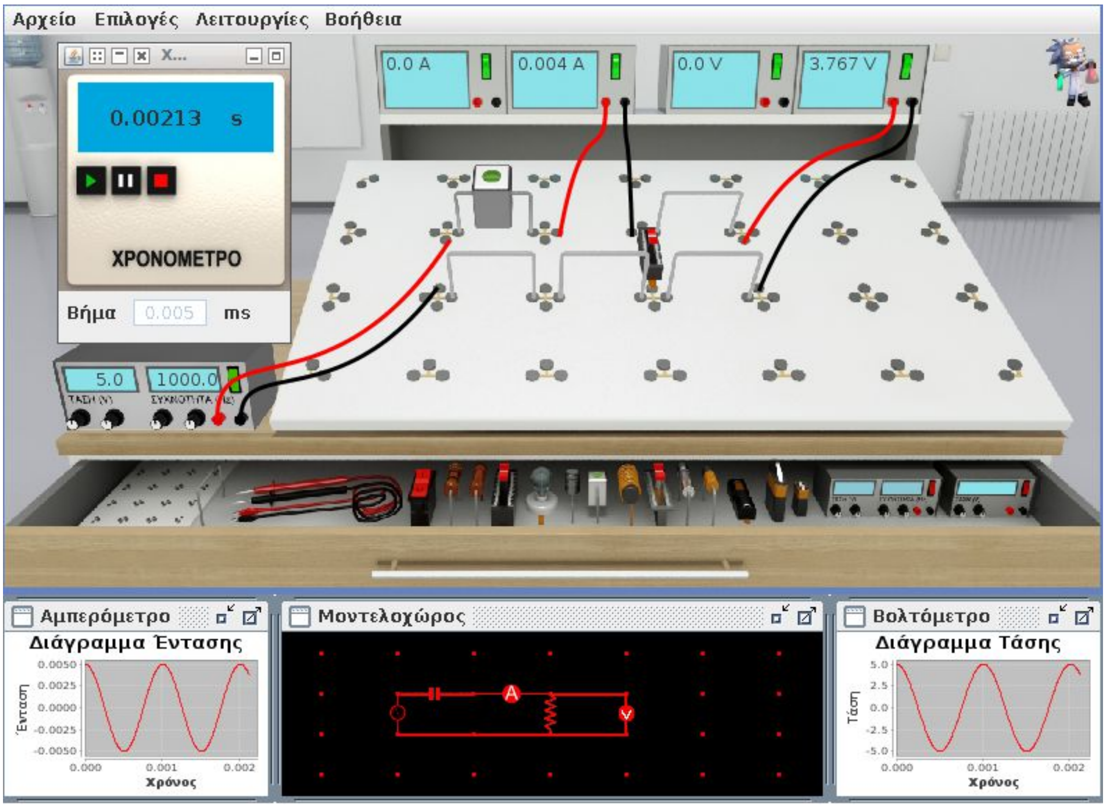

Figure 1. The NOESIS WebLab virtual laboratory environment.

Three experiments were performed in total during this innovative TLS and aspects of scientific experimentation were explicitly taught to the students who were prompted to design each experiment guided by a design activity worksheet and then perform the experiment they had designed guided by an implementation activity worksheet. The design and implementation worksheets of the first experiment of the TLS followed a structured inquiry pattern. Initially the design activity worksheet contained an initial problem-question in order to provoke students' questioning. The students were then guided to design an appropriate experiment to solve the problem, being provided scaffolding through appropriate questions of the worksheet, reflect upon their previous knowledge in order to find the theoretical knowledge being applicable to the problem, take a decision on the physical quantities needed to be measured, design an appropriate circuit to take necessary measurements, draw it schematically and decide on the experimental procedure for measuring the quantities needed. The experiment implementation worksheet, which followed this first experiment, initially asked the students to construct the circuit they had drawn schematically in the virtual laboratory environment. Then, students were asked to carry out the experimental procedure they had designed, understand and analyze their measurements, formulate the answer to the initial problem and evaluate their predictions. After having completed each experimentation phase, students were prompted to reflect upon the experimentation steps they had carried out in order to reach the final result. A part of the first design activity worksheet is included in Appendix A.

The TLS should allow students to take decisions about the experimental procedure they would follow, by designing their own circuits, constructing them in the virtual environment and exploring their behaviour, rather than reading about, constructing and exploring given circuits. Therefore, the guidance embedded in the activities varied during the TLS. After the first unit, instruction gradually moved towards guided and finally open inquiry as the TLS was progressing and students became more familiar with the scientific experimental procedure (Zion & Mendelovici, 2012). Appendix B shows the activity worksheet of the last unit which followed an open inquiry pattern with a given initial problem.

During instruction students were involved in reflection upon the actions carried out as part of the experiment design and implementation procedures. The teacher guided the students and explicitly named and described each procedure followed by them. Also, one of the units, halfway through the TLS, contained a reflection on the experiment design and implementation process, during which the teacher and students reviewed and after discussion wrote down the scientific experimental design and implementation procedures applied in the previous units.

A pre-/post-test design was implemented, with pre- and post-tests assessing both students' procedural knowledge via a paper-and-pencil written questionnaire and experimentation skills in AC electric circuits via the design and implementation of certain experiment tasks. The questionnaire contained 18 multiple-choice questions about various aspects of experiment design and implementation. All questions were expressed in the context of electric circuits and did not require any knowledge other than the one students had received instruction for in previous school years. The questionnaire assessed aspects of experimentation, such as forming hypotheses, variable identification, choosing materials and instruments, describing experimental procedure, obtaining results, forming and evaluating conclusions. The same questions were used both as a pre-test and a post-test but the order of the questions in the pre-test differed from that in the post-test. Also, the order of the answer items for each multiple-choice question in the pre-test differed from that in the post-test to minimize the effect of any memorizing strategy students might have adopted. The questionnaire was developed and verified for content validity and reliability in a previous pilot study (Taramopoulos & Psillos 2020). Measurements of Cronbach's alpha for the current study gave values of 0.756 (pre-test) and 0.778 (post-test), indicating sufficient reliability. The students' scores were adjusted to a 100-point scale and the mean test score was then calculated.

The students’ experimentation skills were assessed through a pre- and a post-test task in-class assignment. Before the beginning of the TLS, students were asked to design and perform an experiment in order to answer if Ohm's law for resistors holds in AC circuits similarly to DC circuits (pre-test task). The post-test task asked the students to design and implement an experiment in order to answer whether a circuit, with an inductor connected in parallel to a capacitor, behaves in AC as a bandpass filter. Both tasks were accompanied by appropriate worksheets which did not contain any guidance other than the initial question and a prompt to design and perform an experiment to answer it describing in detail their actions. Two experienced researchers scanned the worksheets for statements which showed skills in any of the experiment design and implementation phases and then classified their statements according to a three-level Likert scheme for each experimentation phase. A lack of statement or a statement which did not contain any correct experimentation elements was classified as level 1, a partially correct or a partially complete statement as level 2 and a correct and complete statement as level 3. This level classification was considered to be a process which sampled students' experimentation skill level at each experimentation phase. Students' levels were averaged and then adjusted to a 100-point scale.

RESULTS

We have avoided using parametric tests in the comparisons to ensure that our results do not depend on the assumptions of these tests and are not affected by our small sample size or other characteristics of our data. We therefore based our conclusions on the overlap of the 95% confidence intervals, which were calculated using BCa CI (Bias Corrected and accelerated Confidence Intervals) with 1000 samples, randomly selected from the current research sample. In effect, this technique, known as bootstrapping, treats our sample data as a population from which 1000 random smaller samples are taken. From these samples, the properties of the sampling function of our data, like the 95% confidence intervals, can be estimated avoiding possible bias due to our small sample size (Efron & Tibshirani, 1993). No overlap between compared BCa Confidence Intervals implies that the means come from different populations and are significantly different at the $p<0.01$ significance level (Cumming & Finch 2005). Significant overlap of the order of half the length of the confidence interval or greater implies that there is no statistically significant difference between the means of the compared populations ($p>0.05$) (Cumming 2012).

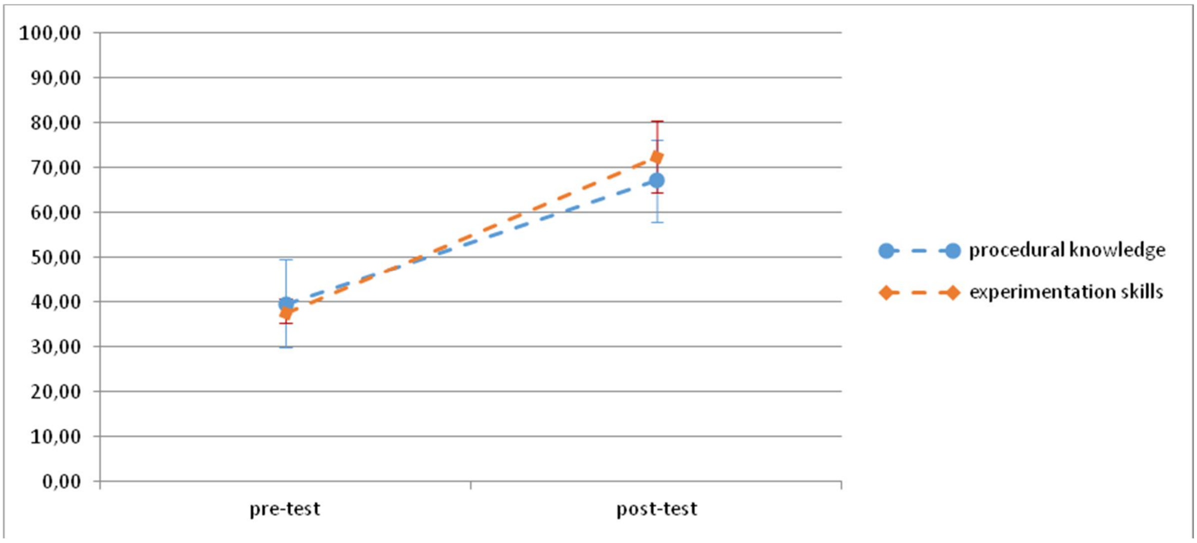

Figure 1. Pre-and post-test scores for procedural knowledge and experimentation skills.

Comparing the students' scores in the procedural knowledge pre-test questionnaire with the scores from the worksheets in the pre-test task we have found that there is significant overlap in BCa CIs and therefore these scores were statistically similar (Mprocpre=39.78 [29.87,49.70], Mtaskpre=37.73 [35.28,40.88]). The same was true for the scores in the procedural knowledge post-test with the scores from the post-test task worksheets (Mprocpost=67.33 [57.88,76.16], Mtaskpost=72.45 [64.64,80.40]) (results are shown in Figure 1).

There was a statistically significant increase for both the procedural knowledge and the experimentation skills of students between the pre- and post-test scores (no BCa CIs overlap, $p<0.01$) with a strong statistically significant positive correlation between them, $r=0.91$ [0.86,0.99].

DISCUSSION AND CONCLUSIONS

In order to help students, understand the procedures of scientific experimentation in AC electric circuits during normal in-class instruction, an innovative inquiry-based technology-enhanced Teaching Learning Sequence (TLS) was developed. The TLS, which utilized an open virtual AC circuit laboratory environment, was enriched with reflection metacognition-activities and aimed at the development of both procedural knowledge and experimentation skills. Results show that after the TLS, students seem to have significantly developed both their procedural knowledge and their experimentation skills. Thus, our TLS appears to be effective in helping students advance their procedural knowledge on designing and implementing experiments in AC circuits and simultaneously develop students' experimentation skills on performing aspects of the scientific experimentation procedures.

Our results also indicate that the development of procedural knowledge may correlate well with the development of experimentation skills. Thus, in the context of a technology enhanced inquiry-based TLS it seems that by enhancing students' procedural knowledge, e.g. through explicit teaching in the classroom, and involving students in designing and implementing experiments through investigative activities, the experimentation skills of secondary school students may also be enhanced. Therefore, the term "practices" may justifiably be used instead of the term "skills" to emphasize that engaging in scientific investigation requires not only skills but also knowledge that is specific to each aspect of experimentation (NRC, 2013).

Our results, combined with the results of previous studies (Taramopoulos & Psillos, 2020), in which it is reported that after instruction utilizing such a TLS the students' cognitive knowledge is also advanced, seem to indicate that by enriching instruction with the explicit teaching of the experimentation procedures, teaching may achieve several goals simultaneously: advance students' cognitive knowledge, advance their procedural knowledge and develop experimentation skills. In this way students may acquire the knowledge and the skills to investigate physical phenomena on their own and through this acquire a deeper understanding of physical sciences. Hence our results put forward the claim that by including explicit teaching of the experimentation procedures combined with metacognition-enhancing activities as part of the instruction, secondary school students' experimentation skills and knowledge may be significantly improved, in accordance with other recent similar reports (Vorholzer et. al., 2020). More research is necessary to reinforce this claim given the limitations of our current study, such as the lack of comparison with implicit teaching of experimentation procedures.

Examining the relation between the development of students' procedural knowledge and experimentation skills, a strong correlation is observed. This is indicative of the fact that both are developed simultaneously during the TLS. However, it does not necessarily imply any causal relation between them, nor does it provide clues as to how this may have been achieved during the TLS. Further investigation is necessary to clarify the nature of this correlation.

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REFERENCES

Brinson, J.R. (2015). Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. *Computers & Education, 87*, 218-237.

Cumming, G.& Finch, S. (2005). Inference by eye: Confidence intervals and how to read pictures of data. *American Psychologist, 60(2),* 170-180.

Cumming, G. (2012). Understanding the new statistics: Effect sizes, confidence intervals, and meta-analysis. New York: Routledge.

Efron, B,& Tibshirani, R. (1993). An introduction to the bootstrap. New York: Chapman and Hall.

Garratt, J. & Tomlinson, J. (2001). Experiment design - can it be taught or learned? *Univ. Chem. Education, 5*, 74-79.

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*, 179-201. https://doi.org/10.2307/1170753.

Lefkos, I., Psillos, D. & Hatzikraniotis, E. (2011). Designing experiments on thermal interactions by secondary students in a simulated laboratory environment. *Research in Science and Technological Education*, *29*, 189-204.

Molohidis, A., Lefkos, I., Taramopoulos, A., Hatzikraniotis, E., & Psillos, D. (2015). Web-based Virtual Labs: A Cosmos-Evidence-Ideas as a Design Framework Leading to Good Practice. In M. Helfert, M. Restivo, S. Zvacek & J. Uhomoibhi (Eds.), *Proceedings of the 7[th] International Conference on Computer Supported Education* (v.1 pp. 418-423). Lisbon: CSEDU.

National Research Council (2013). Next Generation Science Standards: For States, By States. *Washington, DC: The National Academies Press*. https://doi.org/10.17226/18290.

Psillos, D. & Kariotoglou, P., (2016). Theoretical Issues Related to Designing and Developing Teaching-Learning Sequences. In D. Psillos & P. Kariotoglou (Eds.), *Iterative Design of Teaching-Learning Sequences* (pp. 11 - 34).https://doi.org/10.1007/978-94-007-7808-5_2.

Ruten, N., van Joolingen, W.R. & van der Veen, J. T. (2012). The learning effects of computer simulations in science education. *Computers & Education, 58,* 136 – 153.

Taramopoulos, A., Hatzikraniotis, E. & Psillos, D. (2011). Designing virtual experiments in electric circuits by high school students. *Proceedings of the 9th International Conference of the European Science Education Research Association* (ESERA), pp 186-190.

Taramopoulos, A., & Psillos, D. (2020). Developing Scientific Experimentation Skills in Secondary Education Students,. *Abstracts of the 2020 GIREP Webinar, Topic 2-Experiments and lab work in teacher education*. pp.4-5 https://drive.google.com/drive/folders/1ou15a2pwAQcCKASeVPGFU3JTcCnN-8FM (last accessed 17 Jan 2021).

Vorholzer, A., von Aufschnaiter, C. & Boone, W.J. (2020). Fostering Upper Secondary Students' Ability to Engage in Practices of Scientific Investigation: a Comparative Analysis of an Explicit and an Implicit Instructional Approach. *Res Sci Educ, 50*, 333-359. https://doi.org/10.1007/s11165-018-9691-1.

Zion, M., & Mendelovici, R. (2012). Moving from structured to open inquiry: Challenges and limits. *Science Education International, 23 (4)*, 383-39.

Appendices

Appendix A

A part of the first structured inquiry, experiment design, activity worksheet:

I. Experiment Design

Activity 2 (physical quantities recognition)

Which quantities will be needed to be measured in the output of the circuit which will be constructed? (A. dependent variable recognition - physical quantities recognition dimension)

....

....

Since we want to explore what happens in both high and low AC frequencies we will have to change a certain physical quantity during our experiment. So, which physical quantities do we need to change in order to observe the changes in the quantity measured in the output? (B. independent variable recognition - physical quantities recognition dimension)

....

....

When we conduct an experiment we do not alter many variables simultaneously, because if we do so and a change occurs in a measured quantity then we will not know which variable we changed resulted in the change in the measured quantity. Thus we wish to preserve constant all the rest of the quantities which affect the measured quantity. Which quantities need to remain constant in our experiment? (e.g. the amplitude of AC voltage, time of measurements, instrument properties) (C. recognition of variables which need to be controlled - variable control strategy - physical quantities recognition dimension)

....

....

* What are the 3 actions, the 3 steps done in activity 2? (reflection activity)

A)___________________________

B)___________________________

C)___________________________

(Activity 2 conclusion: In order to design an experiment it is necessary to find which quantities are involved, A. which ones should be measured, B. which should be altered, and C. which ones should be kept constant.)

Appendix B

A part of the last open inquiry activity worksheet:

I. Experiment Design

Based on the behaviour of RC and RL circuits in AC, what do you think happens when a resistor (R), a capacitor (C) and an inductor (L) are connected in series? Which AC frequencies have the highest voltage amplitude in the output and why?

....
....

How can you check experimentally the hypothesis you made above? Design an appropriate experiment. Describe your design below in detail.

....
....
....
....

II. Experiment Implementation

Open the virtual electric circuit laboratory in your computer and perform the experiment you designed above. Follow the steps described, record and process your measurements, report the results and state your conclusion below.

....
....
....
....

Does your conclusion agree with your prediction? If not, why is there a discrepancy?

....

UNDERSTANDING THE EFFECT OF MICROORGANISMS ON HUMAN HEALTH: A DIDACTICAL PROPOSAL FOR SCIENCE EDUCATION

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Understanding the effect of microorganisms on human health is essential to change people's thoughts and hygiene habits. This educational goal becomes even more significant nowadays, due to the global pandemic caused by COVID-19, where day-to-day citizens' hygiene practices have become even more relevant for public health. Furthermore, science teachers take on a special role in promoting teaching and learning strategies. They also provide resources that raise students' awareness of this theme. The didactic sequence "Effect of Microorganisms on Human Health", designed and evaluated during a Research and Development (R&D) project, presented an innovative educational proposal regarding Microbiology in Natural Sciences of the 6th grade in Elementary Education (11 years old students). The sequence includes a set of activities and educational resources that study the effects of microorganisms on human health in an innovative way. Subsequently, to ascertain the scientific and didactic quality of the designed activities and educational resources, the educational contribution of the sequence was evaluated, through the involvement of two researchers of the scientific community: one in Science Education and the other one in Microbiology. The perceptions of the two researchers about the scientific and educational potential usability of the sequence were collected through an online survey and an online interview. Data analysis allowed to present and discuss the potentialities, constraints, and suggestions for improving activities and educational resources from a scientific and educational point of view. Thereby, it is intended with this article: i) To present a didactic sequence that integrates didactic activities and resources on Microbiology; ii) Discuss the potential contributions of activities and educational resources proposed at the level of students' awareness of the effect of microorganisms on human health.

Keywords: Health Education; Science Education; Teaching and Learning Sequences

INTRODUCTION

Understanding the effect of microorganisms on human health is relevant today, due to the global pandemic caused by COVID-19. Thus, this project aimed to develop (conceive, evaluate and improve) a didactic sequence entitled "Effect of Microorganisms on Human Health" (EMiSH), with the purpose of contributing to the improvement and / or educational innovation of a context of the 2nd cycle of basic education with the (lack of) awareness of Natural Sciences students in the 6th year of schooling about the effect of microorganisms on human health.

The educational problem was identified in a class of the 6th grade, during the phase of characterization of the educational context, where it was possible to observe the students', behaviors regarding to food preservation habits (eg ways of storing and transporting food to school), verifying that some students had healthy habits (ex. use of thermal bags), while other revealed unhealthy habits (ex. such as the identification of spoiled food in the backpack). In view of this situation, it was considered essential to address some problems related to inadequate food conservation, motivating them to learn about the importance of food preservation in preventing diseases due to microorganisms, as well as making a more comprehensive approach to related topics with health education, associated with the contents of the Microbiology area.

Taking into account the educational problem and the purpose of the study, a research question was established for the project to be carried out: *How the teaching and learning activities of microbiology conceived within the scope of the didactic sequence, may contribute to an awareness of 6th grade students about the effect of microorganisms on human health and, thus, for the development of their skills?*

It is considered essential that children are aware of this issue, due to the topicality of the topic. However, due to COVID-19 and the changes that were necessary to be made during the Supervised Pedagogical Practice intervention period, it was not possible to implement the sessions with the students.

THEORETICAL FRAMEWORK

Schools, in general, and science teachers, in particular, should develop health education projects with the purpose of promoting impact on students' health behaviors (e.g., conservation of food in their school bags). In fact, due to different social circumstances of students (e.g., lack of parents' and family health literacy), school ends up having an important role on changing children' behaviors (e.g., improvement of children' health literacy) (Esteves & Anastácio, 2010). In this way, it is considered that it would be pertinent to link health education with the contents to be addressed during the current academic year, in the discipline of Natural Sciences, with the 6th grade. Also taking into account the educational problem, it was decided to link health education with microbiology.

In Portugal, science teachers can address, in a flexible curricular way, "The impact of microorganisms in human health" theme in "Natural Sciences" subject in Elementary Education. During the school year of 2019/2020, an in-service science teacher has identified an educational problem, during the characterization of the educational context at the 6th grade (a class of 27 students with ages between 10 and 11 years old). Specifically, it was possible to observe the students' behaviors regarding to food conservation habits (e.g., food storing and transportation to school). Some students had healthy habits (e.g., use of thermal bags to carry their food), while other revealed unhealthy habits (e.g., existence of spoiled food in the backpack) (Carvalho, 2020).

Microbiology is considered, according to Bernardi (2019), as the scientific area that studies the role of microorganisms in the world, especially when it comes to society, the human body and the environment. Microorganisms are considered a set of microscopic-sized organisms that inhabit diverse ecosystems and have a wide variety of shapes, sizes and functions. Gonçalves (2012) distinguishes two types of microorganisms: useful and pathogenic. The useful microorganisms do not cause disease and, in addition to their usefulness in food production, are also useful in health promotion and in medicines and vaccines production. On the other hand, pathogenic microorganisms can cause diseases, of greater or lesser severity, according to the resistance characteristics of the host. Mafra and Lima (2012) state that students tend to consider that microorganisms represent the only cause for diseases appearance. This image that students have of microorganisms must be (de)constructed and, therefore, it was considered that it would be relevant to address the alternative conceptions (Martins et al., 2007) of students about the effect of microorganisms on human beings. In addition to these concepts, it was considered essential to integrate activities that included practical, laboratory and experimental work (Martins et al., 2007), as well as the involvement of the scientific community (Espada, 2007).

It should be noted that the participation of the scientific-technological community in school is one of the best ways to develop scientific skills, which was what was intended to be done through the presence of a professional in one of the sessions of the didactic sequence (Espada, 2007). The promotion of contact between the school and elements of the scientific community is becoming more common, as it is one of the best ways to develop scientific skills and adequate conceptions about science and it is also known that, due to their experience, scientists are in a crucial position to help science education at school (Seabra & Vieira, 2016).

In this project, in addition to integrating elements of the scientific community in one of the sessions of the didactic sequence developed, they were also integrated in the evaluation phase of the project, in which it was possible to collect their positive and/or negative perceptions at the didactic and scientific knowledge about the didactic sequence and its resources. This was crucial in order to develop the best and most appropriate didactic sequence and so that it could, in this way, be adopted and adapted, in the future, by other science teachers.

METHODOLOGY

A research and development (R&D) methodology (Wang & Hannafin, 2005) was adopted to develop an artfact – the activities and resources integrated on the didactic sequence EMISH "Effect of Microorganisms on Human Health". By an interactive process of design, testing and evaluation process, the EMISH sequence was developed during two R&D phases: first phase – conception of the activities and resources (Table 1); second phase - scientific and didactic evaluation of the didactic sequence with the participation of two researchers of the scientific community (one from Microbiology and other Sciences' Didactic).

Due to the pandemic state caused by COVID-19 in Portugal, it was decided to adapt the activities for Distance Learning, taking advantage of the circumstances of Basic Education in Portugal (Assembleia da República, 2020) and, thus, the first three sessions were designed to be implemented in classroom teaching and the last three for distance learning. All sessions focused on the teaching and learning of Microbiology, taking into account the essential learning foreseen for the 6th year in the discipline of Natural Sciences.

Table 1 - Didactic sequence session, duration and resources (https://youtu.be/5rPRMqIeMpg).

Session	Duration	Description	Resources/materials
1. "What do I think about…?"	50 min.	Survey of students' previous ideas on the themes: pathogenic and useful microorganisms; food preservation and vaccine; use of antibiotics and over-the-counter medications. In this activity i tis also intended to proceed to to the identification and reconstruction of the students' alternative conceptions.	Record sheet of the responses of each student; Diagnostic evaluation questionnaire carried out through the *Typeform* platform.

"Exploring bread molds"	80 min.	Conducting and experimental activity related to the importance of microorganisms (fungi) in food preservation (bread).	Experimental activity planning letter; Materials for carrying out the experimental activity.
3. Molds in detail	20 min.	Observation of the results obtained through the experimental activity, under the optical microscope and realization of some questions about what is observed.	Slices of bread resulting from the experimental activity; Microscopes.
4. "What do you do for diseases due to microorganisms?"	30 min.	Research and selection of information and, subsequently, preparation of a bookmark, according to the information collected and selected, through na autonomous work, in pairs.	Guidance for self-employment; Materials for the preparation of bookmarks.
5. "How can I prevent myself?"	30 min.	Viewing a vídeo from a Microbiology professional about and experimental activity related to the importance of proper hand washing and carrying out a task.	Video of a Microbiology teacher.
6. "What did I learn about…?"	20 min.	Assessment of students' learning after the didactic sequence (the questionnaire will be the same as that applied in the activity "What do I think about…?").	Guide for autonomous work; Final evaluation questionnaire carried out through the *Kahoot!* platform.

The evaluation was caried out by two elements from the scientific community – one from Microbiology (assistant professor in a Portuguese public higher education institution) and other in the area of research in Science Didactics (mentor involved in the "design" phase of the didactic sequence) – were involved due to their specific scientific knowledge and expertise in educational projects. Their collaboration in the evaluation process (phase 2), through an inquiry process (online survey and individual interview) allow to collect and analyze the positive and/or negative perceptions about the didactic sequence EMISH and to ensure the identification of problems and, consequently, necessary improvements.

Data was analyzed through content analysis which, according to Bardin (2016), is a technique that has the purpose of interpreting communications and serves to explore, for example, answers to open questions whose content is quickly evaluated by themes. This data was collected through the techniques and instruments presented in Table 2.

Table 2 – Techniques and instruments used for data collection.

Techniques	**Instruments**	**Moments of use**	**R&D phases**
Observation	Researcher's diary	During all moments of contact, synchronously and asynchronously.	Conception
Inquiry	Questionnaire Interview	Performed by the researchers, at the time of evaluation of the didactic sequence.	Evaluation and refinement

RESULTS

Results have shown potentialities, constraints, and improvement suggestions of the sessions developed within the didactic sequence EMISH. Concerning the potentialities, both external researchers (Microbiology and Didactic of Sciences) have agreed that: i) the activities and resources were elaborated in an appropriate way to fulfill the curricular learning objectives to Elementary Education (6th grade); ii) the didactic sequence has the potential to contribute to the students' awareness of the effects of microorganisms on human health. Regarding the constraints, results have shown that it was necessary to carry out several reformulations (e.g., reformulate some aspects to avoid teaching by transmission). Finally, regarding to suggestions for improvement, some were listed by the researchers, divided into suggestions for improving potential (e.g., clarification of aspects related to the implementation of the sessions) and suggestions to minimize constraints (e.g., adaptation of instruments evaluation). These results are presented in more detail in Table 3.

Table 3 – Evaluation of the didactic sequence by the researchers.

Potentialities	Constraints	Suggetions for improving potencialities	Suggestions for minimizing constraints
- Presentation of the didactic sequence; - Relevance of the theme at this and other levels of education; - Suitability for the age group; - Adequacy from the didactic and scientific point of view; Relevance for raising awareness about the theme; - Existence of two different teaching modalities; - Contextualization in everyday situation (eg COVID-19); - Use of different educational resources; - Innovative character of the proposed sessions (eg involvement of the scientific community).	- Need to clarify aspects in the presentation document of the didactic sequence; - Need for reformulations and/or improvements in aspects of a didactic and scientific nature.	- Clarification and reformulation / improvement of aspects in the document sent with the presentation of the didactic sequence; - Clarification and reformulation / improvement of didactic and scientific aspects; - Clarification of aspects related to the implementation of the sessions (eg explaining if the sessions were implemented); - Inclusion of other activities (eg debate on vaccination).	- Clarification and reformulation / improvement of aspects in the document sent with the presentation of the didactic sequence; - Clarification and reformulation / improvement of didactic and scientific aspects (eg transmission teaching characteristics); - Adaptation of assessment tools; - Reformulation / improvement of scientific language (eg. classification of viroses and prions as living beings).

FINAL CONSIDERATIONS

With this study it was possible to ascertain the potential and constraints of a didactic sequence that focuses on the topic of Microbiology in the 6th grade. All aspects mentioned by the experts were analyzed and allowed changes to be made in the didactic sequence. The final version of the EMiSH sequence can (and should) be implemented by science teachers with 6th grade students, to assess the impact of activities on their awareness of the effects of microorganisms on citizens' health.

It is concluded that the didactic sequence EMiSH has the potential to contribute to the awareness of the effects of microorganisms on human health, it was elaborated in an adequate way and, in a global way, it allows to fulfill the objectives that were intended to be achieved with its development. Thus, this didactic sequence can be adopted and / or adapted by other teachers, in order to contribute to the formation of citizens aware of the role of microorganisms in human health.

With regard to suggestions for future research, it is considered essential that the didactic sequence presented is implemented in a real classroom context, since only in this way will it be possible to evaluate the impact of activities on students' learning. taking into account the students' previous ideas on the theme and to make adaptations according to the characteristics of the context where the didactic sequence will be implemented. In addition, it is recommended that other activities be created, which may be in accordance with the suggestions that were mentioned by the researchers who participated in this study, or others that are considered relevant.

As a final reflection, it is expected to contribute to the sustainability of the research path carried out, advancing in the field of science didactic research that has been concerned, among other aspects, with the resolution of significant educational issues for actors and systems, aimed at the sustainability of research.

REFERENCES

Bardin, L. (2016). *Análise de Conteúdo* (1ª ed.). Edições 70. https://madmunifacs.files.wordpress.com/2016/08/anc3a1lise-de-contec3bado-laurence-bardin.pdf

Bernardi, G., Silveira, M. S., Leonardi, A. F., Ferreira, S. A., & Goldschmidt, A. I. (2019). Concepções prévias dos alunos dos anos iniciais sobre microrganismos. *Revista Ciências & Ideias, 10*(1), 55–69. https://doi.org/10.22407/2019.v10i1.974

Carvalho, Ana. (2020). Educação para a Saúde no 2º CEB: conceção e avaliação de uma sequência didática sobre o efeito dos microrganismos na saúde humana. https://ria.ua.pt/

Espada, W. (2007). The Role of the Scientific Community in School Science Education. Rede de Revistas Científicas de América Latina, 32 (8), 510-515. https://www.redalyc.org/pdf/339/33932803.pdf

Esteves, I. & Anastácio, Z. (2010). S*aúde Oral no Jardim-de-Infância: um projecto de investigação-acção* [Paper presentation]. Actas do 3º Congresso Nacional de Educação para a Saúde e do 1º Congresso Luso-Brasileiro de Educação para a Saúde, Covilhã, 1148-1164. https://repositorium.sdum.uminho.pt/bitstream/1822/11213/1/3CNES_Esteves_Anastacio.pdf

Finlayson, O.E., McLoughlin, E., Erduran, S., & Childs, P. (Eds.). (2018). *Electronic Proceedings of the ESERA 2017 Conference. Research, Practice and Collaboration in Science Education*. Dublin, Ireland: Dublin City University. https://researchportal.helsinki.fi/files/122425042/ESERA2017_eproceedings_ALL.pdf

Gonçalves, P. M. M. (2012). *Os Microrganismos no 1º e 2º Ciclos do Ensino Básico: Abordagem Curricular, Conceções Alternativas e Propostas de Atividades Experimentais* [Doctoral dissertation, Universidade do Minho]. Repositório Institucional da Universidade do Minho. http://repositorium.sdum.uminho.pt/handle/1822/24475

Mafra, P. & Lima, N. (2012). Os microrganismos no ensino básico. *Portuguese Society for Microbiology Magazine,* (2). https://repositorium.sdum.uminho.pt/bitstream/1822/32558/1/document_19574_1.pdf

Martins, I. P., Veiga, M. L., Teixeira, F., Tenreiro-Vieira, C., Vieira, R. M., Rodrigues, A. V. & Couceiro, F. (2007). *Educação em Ciências e Ensino Experimental – Formação de Professores*. Ministério da Educação – DGIDC. https://www.dge.mec.pt/sites/default/files/Basico/Documentos/explorando_formacao_professores.pdf

Seabra, M. & Vieira, R. M. (2016). Participação da comunidade científica nas práticas das ciências do 2. º CEB. *Indagatio Didactica, 8*(1), 1229-1246. https://www.researchgate.net/profile/Rui_Vieira7/publication/308903041_Participacao_da_Comunidade_Cientifica_nas_praticas_das_Ciencias_do_2_CEB/links/5820606808ae40da2cb4e06f/Participacao-da-Comunidade-Cientifica-nas-praticas-das-Ciencias-do-2-CEB.pdf

Wang, F. & Hannafin, M. J. (2005). Using Design-based Research in Design and Research of Techology-Enhanced Learning Environments. *Educational Technology Research and Development, 53*(4), 5-23. https://www.researchgate.net/publication/225626676_Design-based_research_and_technology-enhanced_learning_environments_Educational_Technology_Research_and_Development_53_4_5-23

DESIGNING AN INNOVATIVE LEARNING ENVIRONMENT FOR STUDENTS: 'NMR FOR FOOD PROFILING – LONG DRINK, SHORT EXPERIMENT'

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A central concern of promoting scientific literacy is that students acquire scientific knowledge and are enabled to apply it to issues and questions arising in quotidian life to take impartial well-justified decisions. However, identifying and competently evaluating scientific problems requires of them a high degree of specialist knowledge and methodology. One issue that plays a significant role in students' everyday lives is consuming of alcoholic cocktails/long drinks. However, alcohol is addressed within the school curriculum solely in terms of its chemical composition, and only the very general effects of alcohol consumption are studied. Thus, the fundamental subject-specific scientific and methodological aspects of alcoholic long drinks are dealt with superficially, if at all. This paper describes an international interdisciplinary project to develop teaching innovation in the curriculum areas of Chemistry and Nutrition/Consumer Education. Its aim is that, through proactive experimental engagement with NMR spectroscopy, students will become acquainted with and independently apply one of today's cutting-edge scientific research methods. In addition, we aim to improve their evaluative competencies based on scientific evidence by addressing a topic close to their personal experience, which will, in turn, enable them to make well-considered decisions about leading their lives responsibly. To achieve this, a non-formal learning environment, the extracurricular 'ELKE' laboratory, has been set up on the 'Design-Based Research' model. The paper presents the concept of this teaching innovation along with the Design-Based Research process.

Keywords: Interdisciplinarity, Teaching Innovations, Non-formal Learning Environments

INTRODUCTION

A Google search of German-language websites with the term 'Long Drink' generated almost two billion hits (1,960,000,000 on 13 January 2022), including numerous recipes for making them at home. The search produced a vivid snapshot of the cultural popularity of these blends of high-proof spirits such as vodka, gin and whisky with 'mixers' such as fruit juice or carbonated drinks. According to a study by the European Food Safety Agency (Zucconia et al., 2013) young people are especially attracted to alcoholic long drinks containing energy drinks that can pose a cardiovascular health risk (Peacock et al., 2014). As alcoholic long drinks play a significant role in young people's everyday lives within their peer groups, and as these drinks are heavily advertised, it is hard for them as consumers to make well-considered and, preferably, health-promoting decisions. Therefore, the school curriculum should include activities that foster young people's evaluative and decision-making competences, especially concerning alcohol as a stimulant and addictive substance (Inchley et al., 2020). Against the background of research in foodstuffs, biochemistry, and nutritional sciences, it is nevertheless plain that more complex, qualitative, quantitative, and analytic methods are needed to shed light on the ingredients of alcoholic long drinks and their chemical structures. One mainstay of such analysis is nuclear magnetic resonance (NMR), widely used in food profiling (Lamanna, 2013).

DESIGN OF AN INTERDISCIPLINARY TEACHING INNOVATION

Based on the theoretical findings and systematic research, the 'NMR for food profiling - Long Drink, Short Experiment' project was set up to engage with the issues of alcoholic long drinks at theoretical, experimental, activity-based, and interdisciplinary levels. By participating, students were to be systematically motivated to identify the ingredients of alcoholic long drinks, understand their effects on their bodies and, based on the scientific knowledge of the long drinks they had acquired, helped to improve their critical faculties regarding advertising claims about such drinks while assessing and reflecting how on they impinge on their own lifestyles. In this sense it is expected that they will acquire competences in science-based decision-making and evaluation, something which is not only a shared aim of Nutrition and Chemistry teaching but also represents a crucial component of consumer literacy and scientific literacy (Moore et al., 2015; OECD, 2009; Holbrook & Rannikmae, 2009). Conversely, consumer literacy and scientific literacy are fundamental prerequisites for proactive participation in shaping one's own community and creating a sustainable society (Angele, 2017). However, the didactic challenges of devising such a project are multifarious; an interdisciplinary approach is vital to address this many-faceted topic (Aikenhead, 1985). Thus, the question arises of what proportions of theory (in the sense of basic scientific knowledge from the various subject disciplines), applied theory (the transfer of subject specialist and interdisciplinary knowledge to the problems of one's lived-in world) and praxis (understood here to be the implementation of scientific methods of knowledge acquisition such as the experiments around NMR spectroscopy) are appropriate within such a learning experience. Especially in the light of nutrition-related issues, it is also crucial to observe the principle of multidimensionality. In particular, when aiming to develop students' evaluative competence.

As the proposed project constitutes a new concept of subject content and methodology in the field of cross-disciplinary didactics, it will be elaborated in the spirit of Design-Based Research (Euler & Sloane, 2014). The aims are: to create an interdisciplinary learning environment within the practical setting of the students' laboratory; to examine its specific applications; and to develop the concept further. Such an iterative approach facilitates systematic configuration, implementation, and validation, i.e., ongoing re-design of the teaching innovation. In this sense, the interdisciplinary learning environment can be progressively developed, optimizing support for students in acquiring the desired evaluative and decision-making competences for a healthy and sustainable lifestyle (Marchand, 2015, Aikenhead, 1985). Particularly in the light of today's complex and ever-changing social challenges, promoting students' knowledge-based evaluative competence in the field of nutrition issues is a lifelong learning task: enabling people to strike a well-founded balance between consumption of, and abstention from, alcoholic long drinks (Inchley et al., 2020).

CONCEPT OF THE INTERDISCIPLINARY TEACHING INNOVATION – FIRST STEPS OF THE DESIGN-BASED RESEARCH PROCESS

The interdisciplinary concept is still in the early stages; so far, just the first design steps of the Design-Based Research process have been taken. The first practical trials (implementation) are currently taking place, whereby no final evaluation data is as yet available.

Starting from a practical problem (the Problem Statement) and taking into account the theoretical context (Theory), a learning structure/concept will be devised in consultation with specialist scientists, subject didactic specialists and experienced teaching practitioners (Design), trialled with school students (Implementation), evaluated according to aims achievement (Analysis) and developed further on the basis of ongoing findings (Re-Design) (see fig.1).

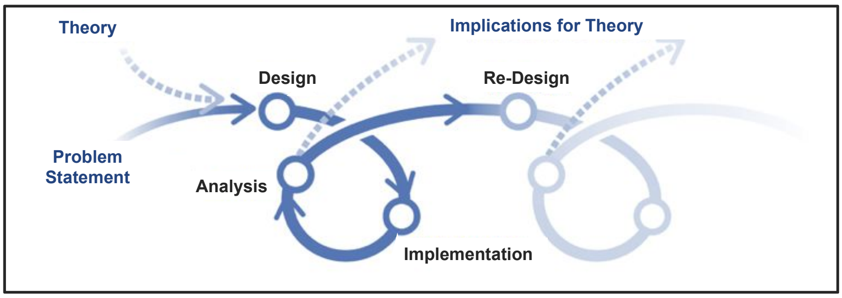

Figure 1. Design-Based Research Process, figure according to Fraefel, 2014.

Such an iterative and cyclic procedure facilitates the successive elaboration of a learning structure that will, when complete, solve the presented initial problem in a didactically appropriate way and foccus on a specific learning objective. Concurrently, theories to substantiate the didactic concept may be deduced, and implications for new theories formulated at every stage. In this sense, the chosen research approach aims to determine: "*how to improve education and learning in authentic educational settings … Further, that explicit goal becomes a day-to-day reference point for collecting and analyzing data, for making modifications to the intervention ..., and at the end of the investigation for determining the extent to which progress has been made (REINKING & BRADLEY, 2008, 19)*" (Euler, 2014, 17). The following account offers detailed insights of the first stages of the Design-Based Research process.

Starting Point: The Problem Statement

As far as school praxis is concerned, Chemistry teaching and Nutrition and Consumer Education both address the thematic complex 'foodstuffs', e.g., alcoholic long drinks, but independently, from different points of view, and with different emphases. While Chemistry lessons concentrate on examination and analysis of constituent substances, Nutrition Education focuses on the provision and consumption of foodstuffs and their effects upon the human body. Thus, knowledge is acquired in isolated fragments while interrelationships remain not perceive. This is where the project intervenes: combining the two approaches to close gaps in school education, addressing modern scientific analysis and its relevance to social and individual consumer habits (see fig. 2).

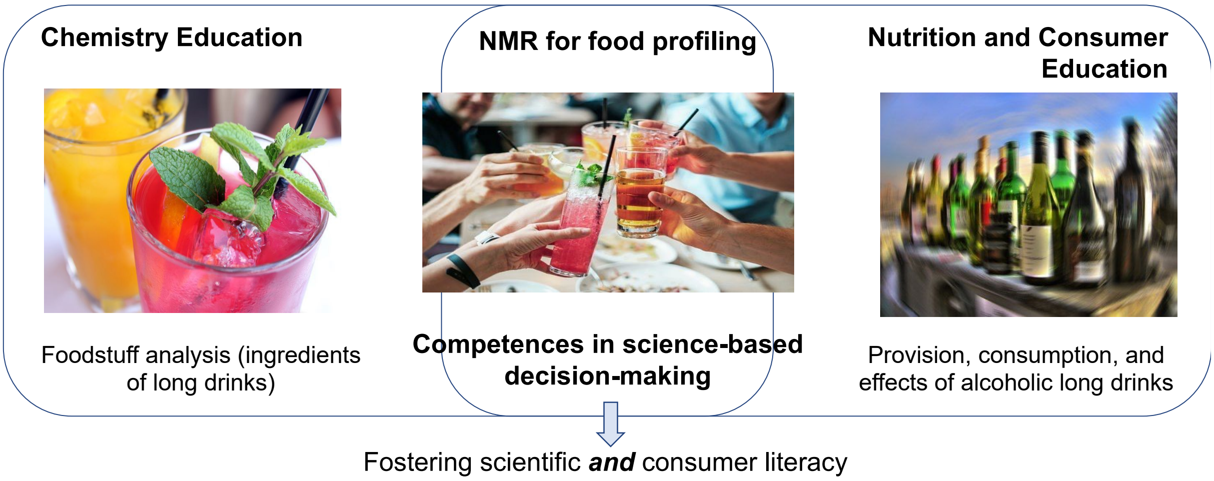

Figure 2. Overview of the project Problem Statement.

The project aims to promote school students' scientifically-founded evaluation competencies by establishing clear and appropriate connections between their scientific and consumer literacy. Through the transfer of the evaluative competencies thus acquired to other socially significant problems, especially in the longer term, the project can enhance the scientifically-based and responsible participation of pupils in broader society.

Theory

As described above, scientific literacy and consumer literacy enhance pupils' ability to make science-based decisions that are important for their active participation in society (e.g., Holbrook & Rannikmae, 2007; Marks, Stuckey & Eilks, 2014; Hofstein, Eilks & Bybee, 2011). Looking at the objectives of science literacy and consumer literacy, both subject matter and analytic methods are relevant; the specific topic, 'alcoholic long drinks', plays a significant role in young people's everyday life and youth culture (e.g., Zucchonia et al., 2013; Peacock et al., 2014; Inchley et al., 2020). Furthermore, NMR spectroscopy presents a cutting-edge scientific research method; pupils become acquainted with this fundamental technique within organic and biochemistry and understand its applications in food profiling (e.g., Lamanna, 2013; Bonjour, Pitzer & Frost, 2015; Bonjour et al. 2017). Inasmuch as non-formal learning environments (an extracurricular student laboratory) are used, it is possible to employ different detection methods (qualitative and quantitative) and also to conduct multifaceted experiments that can place issues and problems in a broader context (hands-on experience with NMR).

Design

To facilitate the appropriate didactic embedment of the learning experience, an established non-formal learning environment, 'ELKE', was used (Gross & Pawlak, 2020). The German acronym 'ELKE' stands for experimenting (German: "Experimentieren"), learning (German: "Lernen") and acquiring competences (German: "Kompetenzen Erwerben"); ELKE is both a conventional student laboratory and a teaching/learning lab for pre-service chemistry teachers. As a student laboratory, ELKE not only invites participating students to places where real research is happening and thus brings them together with professional research chemists but also, through its competence-oriented educational ethos and curriculum-related topics, offers learning-effective networking with regular school lessons. With the 'NMR for food profiling –

Long Drink, Short Experiment' project, the out-of-school lab ELKE was for the first time extended to host an interdisciplinary learning programme specifically for senior high school students and pre-service teachers. Furthermore, 'Long Drink, Short Experiment' is especially suited to implementation as an interdisciplinary project day in the ELKE lab because here it is possible to carry out not only qualitative and quantitative detection methods but also multifaceted experiments that can place issues and problems in a broader context. In this sense, a multidimensional approach to the topic of alcoholic long drinks can be created, capable of supporting students in the development of discerning evaluative skills founded in multidisciplinary knowledge. The actual project day is divided into six steps comprising both theoretical and experimental phases (see fig. 3).

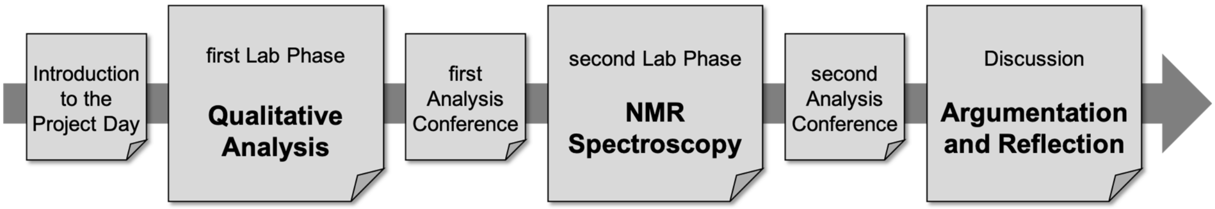

Figure 3. Procedure of the project day, which consists of both introductory and elaborative theory phases as well as practical-experimental laboratory work.

The first devising stage addressed the question of how the topic could be prepared to appeal directly to pupils. After comprehensive literature research and collecting ideas, subject specialists came up with the idea of setting the focus on a specific cocktail/long drink and its varying ingredients within the scenario of a tragic accident (Groß, Kurzbach & Angele, 2020). The refined idea was subsequently discussed with both scientific experts (e.g., with regard to the questions: How, and to what extent, can the topic be purposefully addressed with the help of qualitative experiments? What – else – can the NMR spectroscopy analytic method deliver on this topic?) and with teaching practitioners (e.g., with regard to the questions: How much of the topic be addressed, and in what depth, on the basis of pupils' prior knowledge acquired in Chemistry and Nutrition lessons? Which practical – differentiating – support mechanisms have to be devised and scheduled, so that pupils can develop a scientific understanding of the issues?). As a result of this initial design stage, during which possible experiments and NMR measurements were also carried out, the concept was adapted and amended; the focus was broadened to include analysis of various cocktails/long drinks to reinforce the real-world relevance. Concurrently, this expansion made it possible to devise variable and differentiated tasks within the interdisciplinary learning programme. Finally, the framework scenario was also adapted to reflect the findings of discussions between the various professions: The pupils were to assist Chemistry students in identifying the long drink, Vodka Red Bull, from among 10 different cocktails/long drinks. Thus the main question for the project day was posed as: "Which of the 10 'mystery' samples is Vodka Red Bull?" (*Introduction*). In the *first Lab Phase* (*Qualitative Analysis*) pupils are given a reference sample of Vodka Red Bull and, on this basis, examine the 10 'mystery' samples, initially using qualitative detection methods to identify possible ingredients (see fig. 4).

Cocktails resp. Long Drink	Colour	Test with Fehling's solution	Protein	Ethanol
Vodka Red Bull (reference sample)	brown/ yellow (p)	positive (p)	negative (n)	positive (p)
sample 1 (sugar-free Red Bull)	p	n	n	n
sample 2 (Mojito)	p	p	n	p
sample 3 (Whiskey Sour)	p	p	p	p
sample 4 (Pina Colada)	n	p	p	p
sample 5 (Vodka Red Bull) (sample requested)	*p*	*p*	*n*	*p*
sample 6 (Bloody Mary)	n	n	n	p
sample 7 (Vodka Wellness)	n	n	n	p
sample 8 (Cuba Libre)	n	p	n	p
sample 9 (Swimming Pool)	n	p	p	p
sample 10 (Vodka Club Mate)	p	p	n	p

Figure 4. Qualitative investigation of the 10 unidentified samples, and findings of the first laboratory phase; Vodka Red Bull, the reference sample, is in bold type; in brackets, and not revealed to the pupils, are the names of the cocktails/long drinks.

By comparing with the Vodka Red Bull reference sample (fig. 4, 2nd row, in bold type), the pupils can exclude seven samples by means of qualitative analysis (fig. 4, white background). As the remaining three samples (fig. 4, blue background) cannot be distinguished using qualitative experiments, another analytic method is needed: NMR spectroscopy. To prepare them for the second lab phase, pupils are introduced to the essentials of NMR spectroscopy (such aspects as how NMR works and interpreting NMR spectra) and to its importance in food profiling (*first Analysis Conference*). They then measure the spectra of the three remaining samples (*second Lab Phase*). To enable them to interpret the three spectra, pupils are given the spectra of their possible ingredients (among them: vodka, rum, lime juice, caffeine, saccharin, Red Bull). Pupils then compare the spectra of the individual ingredients with those of the three unidentified samples. In this way they first find out which ingredients appear in each sample. Referring to a cocktail recipe book, they can then determine which three cocktails/long drinks they are dealing with, and thereby clearly identify the Vodka Red Bull that they have been seeking (see fig. 5).

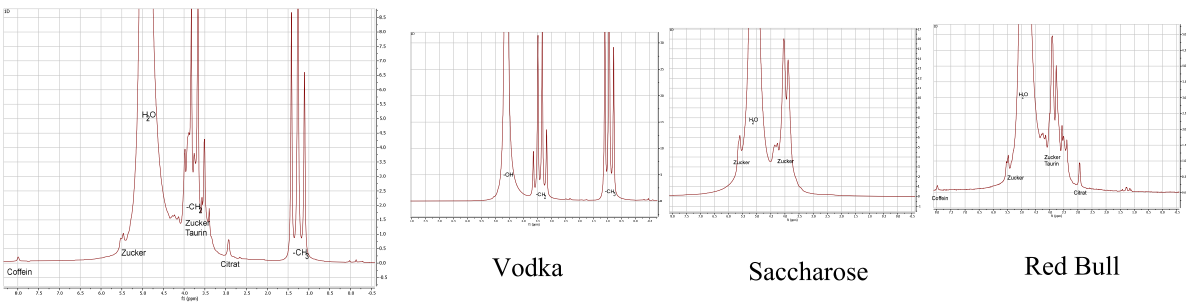

Figure 5. ^{1}H-NMR spectra of Vodka Red Bull (left) and ^{1}H-NMR spectra of different ingredients (right).

The *second Analysis Conference* broadens the field of investigation; pupils use the cocktail recipe book to gather further information about quantities and ratios of ingredients, and the alcohol / energy content of various cocktails/long drinks. While the experimental phase of the learning environment had foregrounded pupils' technical and factual learning, this new knowledge provides the basis for addressing the topic in the spirit of scientific and consumer literacy (*Discussion: Argumentation and Reflection*); using pupils' discoveries during the laboratory and analysis phases and the declarative and procedural knowledge thus acquired, the discussion phase aims to reflect through dialogue on the real-life relevance of the problem-solving task in a multidimensional context. For this, referring to the laboratory journal that accompanies pupils throughout the learning environment and is specifically designed for this phase according to the principle of a decision-making diary (Schmitz & Reiners, 2021), various cues for reflection in four dimensions (Angele et al., 2021) are offered and discussed with pupils: in the first dimension, 'Nutrition', pupils reflect on the qualities and quantities of the cocktail/long drink ingredients and ways in which they can be identified. In the second dimension, 'People', pupils closely address the effects of these ingredients on the human body and assess them with regard to people's health. Finally, pupils work on aspects of the cultural significance of consuming alcoholic long drinks in various social contexts (the third dimension, 'Social Environment') and also on aspects of the natural resources needed for the manufacture of and trade in alcoholic drinks (the fourth dimension, 'Physical Environment'). Bearing in mind the overall aim of the learning environment, these structured cues for discussion and reflection should enable pupils not only to apprehend the scientific background and concomitant social controversy surrounding the important theme of alcoholic consumption in all its complexity but also to develop a well-founded i.e., responsible and situational attitude to alcohol as a consumer product, for themselves and society as a whole. In this way, it may be expected that an intense reflective process is initiated among the pupils, one that will lead them to develop decision-making competences for a healthy and sustainable lifestyle and thereby promote both scientific and consumer literacy.

Implementation

The first trials of the 'NMR for food profiling – Long Drink, Short Experiment' project day are currently being run with senior high school pupils. The process is accompanied by evaluation based on qualitative research design criteria. In the spirit of the Design-Based Research approach, the aim is to elaborate and improve the interdisciplinary learning environment in an ongoing, iterative process in order to achieve the projected aim – to promote pupils' knowledge-based decision-making competences. To gather significant insights for further development, the first design phase is examined both with regard to the fundamental practicability of the innovative learning environment and with regard to possible organisational and content-related amendments and improvements, along with considerations of its learning effectivity for participating pupils i.e., whether and to what extent the promotion of knowledge-based decision-making competence can be achieved in this way. To this end, the project day activities were observed by participating researchers, and both pre-structured interviews and semi-standardised questionnaires were employed to gather views from supervising teachers and participating pupils. Including various survey instruments and points of view in the research methodology produced a methodological triangulation that, at the content-related level, should make it possible to access diverse aspects of the interdisciplinary learning environment. Acquiring such data is, ultimately, the prerequisite for the first comprehensive evaluation of the learning environment – an evaluation that, from this first design cycle, can offer insights regarding its content-related, methodological and organisational suitability but also of the (learning) effectivity.

Re-Design

Once the acquired data have been evaluated, the key findings will be discussed with the various stakeholders (specialist scientists, subject didactic specialists and experienced teaching practitioners), followed by adaptation of various elements of the interdisciplinary learning environment, which are in turn trialled with pupils. In this sense, it can be expected that, through this iterative, cyclic, approach, not only the suitability of the overall learning environment will constantly improve, both in terms of its aims focus and of meeting pupils' needs, but also that new research data will be continually generated that can be used both for the concluding theoretical appraisal and for fundamental theoretical deliberations on the basic underpinning for innovative didactic concepts.

SUMMARY AND OUTLOOK

The research-based development of an interdisciplinary learning programme on the real-life topic of 'alcoholic long drinks', following a Design-Based Research approach, establishes a connection between scientific and consumer literacy within the learning framework, one that both motivates pupils and encourages them develop cross-curricular 'joined-up thinking'. The interdisciplinary didactic approach devised for this topic is transferable to other sociologically relevant issues that, in their complexity, also demand a multifaceted approach (e.g., diverse consumer choices on such criteria as sustainability, climate change etc.). The prerequisite of acquiring knowledge-based evaluative competences is multidisciplinary knowledge that must be didactically developed in all its complexity if it is to serve as the firm foundations of a logically justified weighing-up of objective arguments and thereby as the starting point for well-considered decisions of personal and societal relevance. To this extent, the project described here can offer examples of didactic praxis when the matter in hand is to devise, through research, interdisciplinary learning environments on the burning issues in society in all their complexity, using a problem-solving approach that takes account of the relevant curricular content in an innovative and research-based manner and leads to tangible solutions and/or judgements.

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REFERENCES

Aikenhead, G.S. (1985). Collective decision making in the social context of science. *Science Education, 69*, 453–475.

Angele, C. (2017). Nutrition and consumer education as a constituent part of global education in the light of the new education framework in state schools in southern Germany: The case of Baden-Württemberg. *International Journal of Development Education and Global Learning, 9(*2), 16-28.

Angele, C., Buchner, U., Michenthaler, J., Obermoser, S., & Salzmann-Schojer, K. (2021). *Fachdidaktik Ernährung*. utb.

Bonjour, J.L., Pitzer, J.M. & Frost, J.A. (2015). Introducing High School Students to NMR Spectroscopy through Percent Composition Determination Using Low-Field Spectrometers. *Journal of Chemical Education*, *92*, 529−533.

Bonjour, J.L., Hass, A.L., Pollock, D.W., Huebner, A. & Frost, J.A. (2017). Bringing NMR and IR Spectroscopy to High Schools. *Journal of Chemical Education, 94*, 38−43.

Euler, D. & Sloane, P.F.E. (Eds.) (2014). Design-Based Research. *Zeitschrift für Berufs- und Wirtschaftspädagogik, Beiheft 27*.

Euler, D. (2014). Design-Research – a paradigm under development. *Zeitschrift für Berufs- und Wirtschaftspädagogik, Beiheft 27*, 15-41.

Gross, K. & Pawlak, F. (2020). Using video documentation in out-of-school lab days as an ICT learning and diagnostic tool. *World Journal of Chemical Education, 8*(1), 52-60.

Groß, K., Kurzbach, D. & Angele, C.M. (2020). NMR for food profiling – Long Drink, Short Experiment: Ein interdisziplinärer Zugang zur Förderung von Urteilskompetenz. *Haushalt in Bildung & Forschung, 4*, 79-96.

Holbrook, J. & Rannikmae, M. (2009). The Meaning of Scientific Literacy. *International Journal of Environmental & Science Education, 4*(3), 275-288.

Holbrook, J. & Rannikmae, M. (2007). The nature of science education for enhancing scientific literacy. *International Journal of Science Education, 29*(11), 1347– 1362.

Hofstein, A., Eilks, I. & Bybee, R. (2011). Societal issues and their importance for contemporary science education – A pedagogical justification and the state-of-the- art in Israel, Germany and the USA. *International Journal of Science and Mathematics Education, 9*(6), 1459–1483.

Inchley J., Currie D., Budisavljevic S., Torsheim T., Jåstad A., Cosma A. et al. (Eds.) (2020). *Spotlight on adolescent health and well-being. Findings from the 2017/2018 Health Behaviour in School-aged Children (HBSC) survey in Europe and Canada. International report*. WHO Regional Office for Europe.

Lamanna, R. (2013). Chapter Four - Proton NMR Profiling of Food Samples. *Annual Reports on NMR Spectroscopy, 80*, 239-291.

Marchand, S. (2015). *Nachhaltig entscheiden lernen. Urteilskompetenz für nachhaltigen Konsum bei Jugendlichen*. Verlag Julius Klinkhardt.

Marks, R., Stuckey, M. & Eilks, I. (2014). Die gesellschaftliche Dimension naturwissenschaftlich-technischer Sachfragen. Die Perspektive der naturwissenschaftlichen Unterrichtsfächer. *GW-Unterricht, 2*(134), 19–28.

Moore, V., Sumrall, W., Mott, M., Mitchel, E.l. & Theobald, B. (2015). Exploring Consumer Literacy. *The Social Studies, 106*(5), 193-203.

OECD (2009). *Consumer Education. Policy Recommendations of the OECD's Committee on Consumer Policy.* OECD, Paris. Retrieved from https://www.oecd.org/sti/consumer/44110333.pdf (05/2021)

Peacock, A., Pennay, A., Droste, N., Bruno, R., & Lubman, D.I. (2014). "High" risk? A systematic review of the acute outcomes of mixing alcohol with energy drinks. *Addiction, 109(*10), 1612–1633.

Schmitz, L. & Reiners, Ch.S. (2021). Identifying everyday decision situations of learners in science education. In O. Levrini & G. Tasquier (Eds.), *The Beauty and Pleasure of Understanding: Engaging with Contemporary Challenges Through Science Education* (Electronic Proceedings of the ESERA 2019 Conference, pp. 957–965). ALMA MATER STUDIORUM – University of Bologna.

Zucconia, S., Volpatoa, C., Adinolfi, F., Gandini, E., Gentile, E., Loi, A. & Fioriti, L. (2013). *Gathering consumption data on specific consumer groups of energy drinks. European Food Safety Authority*. European Food Safety Agency.

THE ENERGY FIELD APROACH A DESIGN-BASED RESEARCH PROJECT

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Energy is an important topic in middle as well as in high school. Although the understanding of the energy concept is crucial for describing and explaining phenomena, school instruction often fails to transmit and ensure a profound understanding of energy. To address this problem, the energy field approach develops and evaluates a teaching-learning sequence which combines energy with the concept of fields by tracing back traditional energy forms to only two: kinetic and field energy. The emerging concept is based on empirical evidence about students' misconceptions as well as didactical reconstructions of scientific content, leading to so called concept (or core) ideas. These ideas are evaluated and re-designed by conducting and subsequent qualitative analysis of teaching experiments as they represent the essence of the teaching-learning sequence. Already two cycles of (re-)designed sequences have been conducted and evaluated with 6 and 7 students, respectively. The results are promising and give information about learning obstacles as well as benefits of the approach.

Keywords: energy instruction, design-based research, teaching learning sequence

INTRODUCTION

Energy is one of the crosscutting concepts (see also NGSS of the National Research Council, 2021) in physics as well as in physics education not only in Austria. It has great relevance for describing and explaining phenomena from a scientific perspective. However, several studies indicate that despite its global character as one of the big principles in science, students have problems with learning about energy and especially energy conservation (see e. g. Driver & Warrington., 1985; Nordine et al., 2019). Although there are several approaches being developed at the time to address this problem, a valid and evaluated way for teaching this topic has yet to be discovered and manifested. In that sense, the presented project, the energy field approach (EFA), challenges the task to find a more effective approach to energy instruction by developing and evaluating a teaching concept for energy instruction at the end of Austrian high school (grade 12). The poster presented on ESERA Conference 2021, and hence this article, presents the basic ideas of the concept as well as the first two steps of (re-)design and evaluation.

BACKGROUND

The following selection gives a brief outline of the most important difficulties and basic ideas of energy instruction as well as the starting point of the presented project.

Traditional energy instruction usually focusses on teaching various energy forms like kinetic, potential, electrical, chemical, solar or nuclear energy, just to mention a few. Instruction in this way requires the students' ability to interpret and connect all these forms in order to understand the underlying concept which shall lead to a sound understanding of energy conservation. Although the idea of splitting the originally unitary entity of energy into forms is supposed to be useful, simple and practical when talking about phenomena from an energy perspective, evidence shows that this is not the case. Students seem to have problems understanding the concept of energy in this way (Nordine et al., 2019). For instance, students often struggle with making connections between different forms of energy and misunderstand that energy forms are not conserved themselves but only energy in total (Nordine et al., 2011). This obstacle seems to be reflected also in the fact that students often struggle with understanding the role of potential energy as a system property as well as the benefits of arguing from an energy perspective in problem solving and, hence, seldom use energy ideas when trying to explain phenomena. Researcher sometimes criticize that introducing energy forms only is a re-phrasing or re-labelling of the same thing (Swackhamer, 2005). This confusing terminology of not well-defined terms (i. e. forms) of energy seems to lead to learning blackboxes rather than understanding what energy actually is (Nordine et al., 2011; Nordine et al., 2019; Quinn, 2014). All these problems leads to the conclusion that students do not reach the desired level of understanding of energy as an important and powerful crosscutting concept and, hence, the traditional course of energy instruction by introducing different forms (via force, work, golden rule) seems not to be the best way. For a brief overview of the most relevant problems in energy instruction see e. g. Nordine et al. (2019).

Therefore, in order to find a more effective and fruitful way to teach energy, several approaches exist that combine the abstract concept of energy with the concept of fields for the sake of framing traditional (especially potential) forms of energy (see Fortus et al., 2019; Nordine et al., 2019; Rückl, 1991). The energy field approach aligns with this idea and merges traditional forms to only two: energy in movement (kinetic energy) and in fields (all forms of potential energy). This way, energy can be treated more as an underlying global concept (Quinn, 2014).

THE ENERGY FIELD APPROACH

The energy field approach (EFA) is based on the knowledge about difficulties above and combines ideas from already existing curricula to develop an approach that provides an interdisciplinary valid and useful concept for energy instruction on the high school level. The following paragraph gives a brief insight into the main features and concept ideas of the EFA which are obtained in the process of educational reconstruction of energy for the EFA. Parts of the following description are already described in Becker and Hopf (2021).

Basis of the EFA

The EFA traces back different forms of energy to just kinetic and field energy as it is also used in the concepts of Rückl (1991) and Nordine et al. (2019). Thereby, kinetic energy is assigned to moving objects with mass (not photons) and field energy is introduced to be a property of fields. While the former is what is already taught in school, the latter term sums up traditional forms of potential energy, i. e. energy in electrical, magnetic, electromagnetic, gravitational and nuclear fields. Thereby, the EFA covers classical fields like electrical, magnetic, electromagnetic and gravitational fields as well as modern fields such as nuclear fields of quarks and the Higgs field.

The general field

A key feature of the EFA is that energy is only attributed to a so called general field: Charges, magnets, masses and quarks are sources of respective fields (electric, magnetic or quark fields). Two sources (generally of one kind) interact via their fields which overlap/superpose to a so called general field. This field, then, stores the energy of the interaction and can take or give up energy while changing in a physical process. When hearing about the concept students are shown a visualization of the general field following the idea of Fig. 1. Thereby, a field itself is depicted as a circle or ellipse due to limitations in drawing whilst students are told that fields in general are not restricted to a specific area. So as long as possible a field has no specific size and two or more fields hence can superpose. The resultant field is called the general field.

An easy example is the acceleration of two close and repelling magnetic carts which speed up due to the repulsion. While accelerating, energy is transferred from the general magnetic field (as the superposition of the two magnetic fields of the carts) to the movement of the carts which move apart. The same principle applies for a falling ball, where energy is transferred from the general gravitational field (formed by the two fields of ball and earth, respectively) to the accelerating ball. Hence, within the EFA, energy is connected to either a moving massive object or a general field (superposition of two or more fields defined by their respective sources).

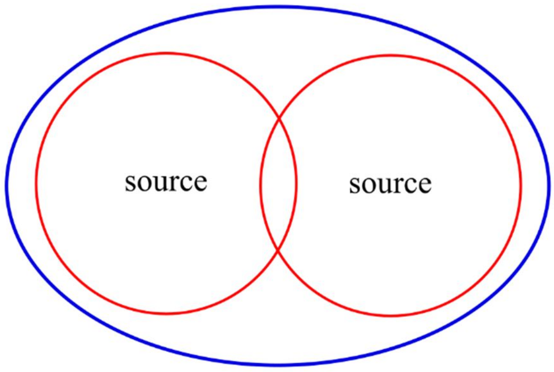

Figure 16. The general field. Two sources (e. g. charges, magnets or masses) interact via their fields (single fields as red circles) and exhibit a resultant general field (blue ellipse). Drawing is limited despite the real size of the fields is ideally infinite.

Direction of energy transfer

When energy is transferred, it can be transferred between fields and moving objects. Thus, processes can be described from an energy perspective by first looking for both, fields and moving objects. Since energy will be found to be in either one of those, energy conservation as the total of kinetic and field energy appears plausible. Furthermore, the EFA provides a simple but effective method to describe the energy transfer process by looking at two indicators: speed (of the moving parts) and distance (of the field sources). By describing changes in these quantities, the energy transfer can be described more easily.

Reasoning on the energy transfer process can be supported by specifying the direction of energy transfer. Therefore, the general field itself plays an active role in phenomena: When two sources interact and a specific process happens (e. g. the ball falling), the general field changes which can be noticed by the distance of the sources changing (ball and earth are approaching). The changing field releases energy to the accelerating ball. By framing the field as an participant (in the sense of a changing system) and describing the processes by means of describing the behavior and change of the field provides two direct advantages compared Newtonian mechanics: First, discussing field and hence energy changes avoids discussing forces and work which was found to be difficult for many students (Jewitt, 2008; Neumann, 2013). Second, assigning an active role to the general field should increase its attractiveness and students' willingness for use when reasoning about phenomena.

Table 2. Traditional energy forms and equivalent EFA terms for different contexts.

Context	Traditional energy form	EFA energy term
repelling magnetic carts	magnetic energy	magnetic field
falling ball or satellite	potential energy	gravitational field
slingshot & firework	elastic & chemical energy	atomic field
decelerating pendulum	thermal & internal energy	micr. movement & atomic field
laser cutter & solar panel	electromagn./solar energy	electromagnetic field
nuclear fission/fusion	nuclear/binding energy	quark field
pair production/annihilation	mass	Higgs field

In addition, the general field cannot only be used when describing the release or uptake of energy but also for specifying the direction, i. e. whether energy is transferred into or out of the field. Thereby, the *tendency* of the general field plays an important role, which means that the field tends to release energy if possible. This, of course, is a rather flexible statement but which should help students understand in which direction a field would change if it was to behave "freely". In other words, if no external forces are applied, the field (system of two or more sources) will change in a way such that it releases energy, i. e. sources move according to the forces of the interaction only. In the case of the falling ball, ball and earth approach and energy is released. In the case of two repelling magnetic carts, they move apart and the magnetic field releases energy. Of course, the other way around would mean an energy transfer into the respective general field (i. e. the case that work has to be done on the system by applying an external force to the sources). In all cases, the general field plays the role of a changing system whose tendency dictates the direction of energy transfer.

Once students can understand this principle, this tendency of a general field to minimize its energy can be used to explain the binding of systems like e. g. atoms or nuclei. Thereby, the atomic (electric) or nuclear (quark) field releases energy to obtain a stable situation that exhibits minimum energy. The following items sum up the most important concept ideas that have just been elucidated:

- Charges, magnets, masses and quarks are sources of a respective fields.
- Two or more sources interact via their fields which superpose to a general field.
- The general field carries energy which can be transferred from or to a moving object.
- There is only kinetic energy and field energy.
- The general field tends (according to its interaction) to minimize its energy: tendency of the field
- The binding of atoms and nuclei is a result of this tendency of the general field.

Table 1 lists different contexts (examples) for processes with energy transfer with the respective traditional energy forms and the corresponding EFA terms.

Research Question

The goal is to develop a teaching concept for energy instruction at the end of high schools. Therefore, the method is embedded within the domain of design-based research and based on the model of educational reconstruction (MER; see Duit et al., 2012). Briefly, a concept consisting of concept ideas and contexts is designed based on knowledge and findings about students' conceptions (about energy and fields) and a clarification and reconstruction of the scientific content.

To design the concept, concept ideas as well as logical connections between them and appropriate contexts (examples, visualizations, etc.) are constructed. Based on the MER, knowledge about students' misconceptions and elements of the scientific structure of the selected content lead to a merged concept which takes difficulties in students' learning into account. The underlying research question based on the developed concept for the EFA does thus ask: How do Austrian high school students understand the concept ideas of the EFA?

METHOD

In order to answer this question, the concept has to be evaluated with regard to clarity and comprehensibility of its concept ideas. Therefore, teaching experiments with students in form of one-on-one interviews are designed and conducted in style of the method of probing acceptance (Jung, 1992). In such an interview, a student receives explanations and is subsequently asked to rate them regarding the plausibility in order to gain information about the appearance of the specific idea (see Fig. 2 for scheme and Fig. 3 for examples). Afterwards, the student is asked to paraphrase the explanation and idea he or she just heard to see whether the content is easy to understand und to get information about the success of transferring the specific input. At last, the student is asked to transfer the idea to a task that treats a specific phenomenon, e. g. an accelerating satellite surrounding the earth. The goal is to observe the

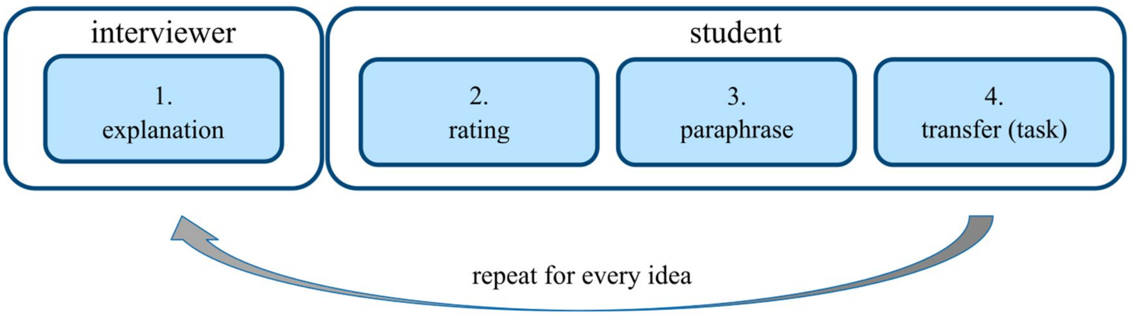

Figure 17. Scheme of the interview procedure according to Jung (1992): Explanation of the concept ideas by the interviewer, followed by rating, paraphrase and transfer of the explanation by the student.

Example 1: microscopic (atomic) fields (shortcut)

1. The elctric fields of atoms superpose. The resulting general field carries energy which is transferred when the field changes.
2. Does this explanation make sense to you? Is it plausible?
3. Please sum up what you just heard in your own words!
4. Please explain where the energy of the moving particles and light of a firework comes from!

Example 2: subatomic fields (shortcut)

1. The mass of electrons and quarks stems from the interaction with the omnipresent Higgs field. The mass of matter mainly stems from the energy stored in the quark field of nucleons.
2. Does this explanation make sense to you? Is it plausible?
3. Please sum up what you just heard in your own words!
4. Please explain what kinds of energy there are before and after the collision of two fast protons at the LHC!

Figure 3. Examples for the steps to explain and evaluate the acceptance and understanding of specific concept ideas of the EFA.

student's reasoning and whether he or she draws on the ideas of the EFA that were just presented. These three steps are repeated for every concept idea (eight in total) which leads to a duration of approximately 2,5 hours for each interview. Every interview is audio recorded.

Afterwards, the interviews are transcribed from the audio recording. Based on audio and transcription, a qualitative content analysis according to Kuckartz (2014) is conducted. According to a coding manual (developed along with the interview guide beforehand), the students' performances are analyzed, coded and summarized in a coding table. By interpreting the rating and paraphrase statements about the acceptance of the concept ideas can be formulated. By analyzing a student's performance on a task (step 4), information about willingness and success in transferring the ideas when solving a problem, and hence, about benefits and obstacles of the ideas can be obtained. Therefore, the analysis provides insights into students' learning and, thus, information about the difficulties and benefits of the concept ideas and contexts. Based on the findings and discussions with experts, suggestions for a re-design can be formulated and implemented into a new version of the concept which then can be evaluated again. This establishes the second cycle of the design and re-design process of the design-based research approach.

Up to now, two cycles of design, evaluation and re-design of the teaching concept have been performed with 6 and 7 students, respectively. This process will repeat until enough information about students' learning is obtained and a satisfactory level of acceptance and comprehensibility is reached which means that no unexpected or new learning obstacles appear and that all concept ideas seem to be useful for learning about energy and fields.

Concept Idea	Phase	S1	S2	S3	S4	S5	S6
Energy in fields and energy transfer	Rating	2	2	2	2	2	2
	Paraphrase	2	2	2	2	2	2
	Transfer 1	1	1	2	0	2	2
	Transfer 2	1	1	2	1	2	1
	…						
	Transfer 3	1	0	2	1	1	2
Thermal energy as kinetic energy	Rating	2	2	2	2	2	2
	Paraphrase	2	1	2	2	2	2
	Transfer 1	2	1	2	2	1	2
	Transfer 2	2	1	2	2	2	2
Electromagn. radiation as field energy	Rating	1	2	2	2	2	2
	Paraphrase		2	2	2	1	2
	Transfer 1		1	2	1	1	2
	Transfer 2		1	2	2	2	2

Concept Idea	Phase	S1	S2	S3	S4	S5	S6	S7
Energy in fields and energy transfer	Rating	2	2	2	2	2	2	2
	Paraphrase	2	2	2	2	2	2	2
	Transfer 1	1	0	1	2	1	1	1
	…							
	Transfer 2	2	0	2	1	0	2	0
Thermal energy as kinetic energy	Rating	2	2	2	1	2		2
	Paraphrase	2	2	2	1	2	1	2
	Transfer 1	2	2	2	1	2	0	2
	Transfer 2	2	2	2	0	1	1	2
Electromagn. radiation as field energy	Rating	1	2	2	2	2	2	2
	Paraphrase	2	2	2	1	2	2	2
	Transfer 1	2	2	2	2	2	2	1
	Transfer 2	2	1	2	2	2	2	2
Quark field	Rating	2	2	2	1	2	1	2
	Paraphrase	2	2	2	1	2	0	1
	Transfer 1	2	2	2	2	2	2	2
	Transfer 2	2	2	2	2	2	2	2
Higgs field	Rating	1	2	2	2	2	2	2
	Paraphrase	2	2	2	2	1	2	2
	Transfer 1	2	2	2	2	1	0	2
	Transfer 2	2	2	2	2	1	2	2

Figure 4. Coding tables (selection) for the results of the first (left) and second (right) cycle of doncuction and evaluation of interviews with 6 and 7 students, respectively (S_i). Students' performance is coded by 2 (good), 1 (satisfactory with only small mistakes) or 0 (insufficient; needs a lot of help). No coding means missing data.

DISCUSSION OF FINDINGS

So far, two cycles of (re-)design and evaluation could be analysed. The data leads to numerous findings and insights about students' understanding when leaning about the concept of the EFA. The following outline shall give a rough overview of the preliminary results.

Aspects to be refined and re-designed

Figure 4 illustrates the results of the first and second cycle of probing acceptance interviews with 6 and 7 students, respectively. Some students of the first circle seem to struggle when it comes to finding the correct type of field and especially to construct the general field in the case of less obvious fields. For example, in the case of the falling ball (first concept idea, transfer 2 in Fig. 4), some students find it hard to think about the earth or the ball as a second field source and sometimes only reason with on single gravitational field instead of a general field. Nevertheless, hints or questions regarding this issue help students to find their way to analyse the whole system.

In those cases where students struggle with reasoning using fields, they still draw on ideas from Newtonian mechanics instead. This happens especially, when the general field or the connection between general field, single fields and sources itself is not understood entirely.

Then, students often argue with an ad-hoc explanation from their mechanics teaching instead of using the EFA concept ideas. It does also appear that some students have difficulties to get the direction of energy transfer right, when they do not have a clear understanding of the role of the general field; for instance, in the case of a satellite surrounding the earth elliptically (cycle 2, concept idea 1, transfer 1). However, it can be observed that students are more likely to draw on the desired explanations when they are taught a more active role of the general field beforehand. This means that wordings like “the field changes”, “releases or takes energy” or “the field expands” seem to support a more field-based thinking in students’ minds such that they draw on the idea of the general field more likely.

Another aspect that can be confusing, is the separation between kinetic and field energy in the cases of thermal and electromagnetic radiation, respectively (see Fig. 4, second and third concept idea). According to the EFA, students are told that electromagnetic radiation (including light) carries field energy since the radiation has no mass but rather is a superposition of electric and magnetic field. This explanation has to be made very concise, otherwise students tend to confuse radiation with kinetic energy. A similar situation appears with thermal energy, where students sometimes struggle to identify the heating of matter with the acceleration of particles or molecules. In that sense, thermal energy is taught to be microscopic kinetic energy of particles instead of field energy. As can be seen form the coding in Fig. 4, students of the first cycle are able to understand this feature better than students in the second cycle (second concept idea). The reason seems to be that a model for the microscopic behaviour of molecules was shown in the first but not in the second cycle. Hence, students are surely able to understand this idea; however, it is better to give them a visualization or a model while explaining in order to ensure that they get the correct idea.

Promising findings

As can be seen from the previous paragraph, there are possibilities to provide different or additional information so that students are more likely to understand the concept ideas correctly. Most of the mentioned problems disappear after another cycle of re-design or at least become more specific. Hence, the evaluation and re-design process will lead to a deeper understanding of students’ understanding, i. e. learning obstacles and benefits of the EFA concept ideas, as the process goes on an eventually produces a concept that can be tested in a class setting.

So far, one can say that students accept and implement the idea of energy stored in fields as well as the role and visualization of the general field in their explanations. Also, the benefits of the EFA in general (simplicity, making sense of traditional energy forms) is noticed and appreciated by most of the students. Even in the case of more complicated phenomena like e. g. fission and fusion (second cycle, quark field, transfer 1 and 2), particle annihilation and creation (second cycle, Higgs field, transfer 1 and 2) or astronomical phenomena of modern physics (e. g. gravitational lens; not coded here), students find it difficult but also triggering and exciting to describe these phenomena by using the EFA ideas. In the end, some students call the approach to be “better than school” or “super exciting” when they are asked to give their opinion on the material.

SUMMARY

The energy field approach (EFA) provides a teaching learning sequence for the high school level that traces traditional energy forms back to kinetic and field energy. Different phenomena can be described from an energy perspective by analysing the energy transfer between field and moving objects. Thereby, the tendency of the socalled general field to minimize its energy plays an important role when determining the direction of energy transfer and when discussing the binding of atoms and nuclei. By linking energy and fields, the traditionally ragged quantity "energy" shall become more accessible, terms and forms of energy are expected to become more meaningful and the concept of energy conservation should become more present in students' reasoning.

Concept ideas and contexts of the EFA have been evaluated in two cycles of probing acceptance interviews (method by Jung, 1992) and provide promising insights into students' understanding when learning about the EFA concept. Especially the general field itself and its active role for describing energy transfer processes in phenomena seem to be helpful for students. Most students are able to paraphrase and transfer the presented explanations in order to explain different phenomena; they draw on the concept ideas in an appropriate way even for phenomena they have not thought about before (e. g. exploding firework or alpha decay). Furthermore, nearly all of the interviews' students find the concept ideas and the concept itself to be plausible and helpful. Of course, implications of the presented findings are limited due to a rather small sample size of the one-on-one interviews. Therefore, further cycles of interviews are currently conducted and further versions of the EFA concept are evaluated and refined. In addition, there will be investigations on how students learn about the EFA concept with a teaching learning sequence in a typical classroom setting. However, recent results show that the EFA concept already supports students' learning about energy. Summing up the findings, the EFA provides a promising concept that is hoped to solve a lot of actual problems in energy instruction.

REFERENCES

Becker, M., & Hopf, M. (2021). Der Energie-Feld-Ansatz: Design-Forschung zur Entwicklung und Evaluation eines Unterrichtskonzeptes für den Energieunterricht der Oberstufe. *PhyDid B-Didaktik der Physik-Beiträge zur DPG-Frühjahrstagung*, *1*.

Driver, R., & Warrington, L. (1985): Students' use of the principle of energy conservation in problem situations. In: Physics Education, 20, S. 171–176.

Fortus, D., Kubsch, M., Bielik, T., Krajcik, J., Lehavi, Y., Neumann, K., ... & Touitou, I. (2019): Systems, transfer, and fields: Evaluating a new approach to energy instruction. In: Journal of research in science teaching, 56(10), S. 1341-1361

Jewett Jr, J. W. (2008). Energy and the confused student I: Work. *The Physics Teacher*, *46*(1), 38-43.

Jung, W. (1992): Probing acceptance, a technique for investigating learning difficulties. In: Research in physics learning: Theoretical issues and empirical studies. Kiel: IPN, S. 278-295.

Kuckartz, U. (2014): Qualitative text analysis. A guide to methods, practice & using software. Los Angeles: SAGE

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. National Academies Press

Neumann, K., Viering, T., Boone, W. J., & Fischer, H. E. (2013): Towards a learning progression of energy. In: Journal of Research in Science Teaching, 50(2), S. 162–188

Nordine, J. C., Krajcik, J. S., & Fortus, D. (2011): Transforming energy instruction in middle school to support integrated understanding and future learning. In: Science Education, 95(4), S. 670–699

Nordine, J. C., Fortus, D., Krajcik, J. S., Neumann, K., & Lehavi, Y. (2019): Modelling energy transfers between systems to support energy knowledge in use. In: Studies in Science Education, 54(2), S. 177–206

Quinn, H. (2014). A physicist's musings on teaching about energy. In: R.F. Chen, A. Eisenkraft, D. Fortus, J. Krajcik, K. Neumann, J. Nordine, & A. Scheff (Hrsg.): Teaching and learning of energy in K-12 education, New York, NY: Springer, S. 15–36

Rückl, E. (1991): Feldenergie: ein neues didaktisches Konzept. BI-Wiss.-Verlag.

Swackhamer, G. (2005): Cognitive resources for understanding energy. Url: https://modeling.asu.edu/modeling/RESOURCES_10-03.pdf, (05/2021)

A POSSIBLE ROLE OF THE SECOND QUANTUM REVOLUTION IN PHYSICS EDUCATION

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We present a teaching/learning sequence on the introduction of concepts of quantum computation and information which we have experimented with fourth and fifth grade students in Italy. The sequence attempts to bring fields such as propositional logic, physics and probability, which are traditionally scarcely related within the secondary school curriculum, under a unified perspective. Our work aims at understanding whether students are able, if guided within a research-based teaching/learning sequence, to first grasp such integration in the classical context, and then problematize it and extend it to the quantum domain. The analysis of the experimentation data, while providing encouraging indications, shows very rich and complex patterns, allowing to identify activities which may be more productive for students and to uncover weak points and student's difficulties.

Keywords: Teaching Learning Sequences, Technology Education, Interdisciplinarity

INTRODUCTION AND THEORETICAL FRAMEWORK

In the Italian national curriculum guidelines (MIUR, 2012) on the competencies that students should acquire at the end of the "Liceo Scientifico" (science-oriented secondary school), three interdisciplinary aspects are identified: mastering the fundamental procedures of logical-mathematical thinking; becoming familiar with methods of investigation typical of the physical sciences; understanding the methodological value of information technology in the formalization and modelling of complex processes and in the identification of solution procedures. We present a Teaching-Learning Sequence (TLS) attempting to interpenetrate these three aspects in the context of the paradigm change requests expressed in the Strategic Agenda of the Quantum Flagship (European Quantum Flagship, 2020): introducing students to "*the paradigm shift from quantum theory as a theory of microscopic matter to quantum theory as a framework for technological applications and information processing*".

The change of perspective implied in the above statement, when taken with its full implications, suggests the necessity to highlight the limits of the classical paradigm not only strictly within the field of physics - with the development of quantum theory - but also in the areas of mathematical logic, probability theory, information theory. The profound link between classical mechanics and propositional logic was explored by Isham (2001) and a simple redefinition of language terms allows to extend the discussion to concepts of probability theory. When brought into an educational environment, these reflections allow to highlight deep ties between the paradigm of classical physics and the architectures and procedures of classical computers and pave the way for the natural question of whether such unity can still be preserved with the advent of quantum theory. Those aspects of quantum physics which may appear as limits to the human possibility of understanding and knowing (limits of classical propositional logic for systems such as Stern-Gerlach or birefringent crystals, and limits of probability theory, for example in the case of the interference of electrons from a double slit), and as such may constitute epistemological obstacles to learning (Malgieri et al., 2017) can then be framed in a positive perspective, allowing the emergence of a new unitary picture and new possibilities embodied by quantum computation and quantum communication. The principles of quantum theory, and in particular superposition and entanglement, therefore become the heart of a path towards an overcoming of the classical paradigm not only on the side of physics, but in multiple directions. Thus, a TLS exploiting such connections may on one hand introduce students to interpretive and formal tools suitable for modelling contemporary technological advancements, and on the other hand open a broader and fertile theoretical and cultural perspective.

STRUCTURE OF THE TLS

The structure of the TLS is schematically reported in Table 1.

Table 1. Structure of the TLS.

Topic and time employed	**Experimental and simulation activities**	**Methods**
1. Introduction to quantum physics in the contexts of polarisation and the hydrogen atom (Distance Learning, 9 h)	Polarizing filters and birefringent crystals. Thought experiments. Simulations of single photons experiments	Individual worksheets, Generation of hypotheses and evaluation of student answers to the worksheet items in a full class discussion, Lecture
2. The physics of computation and its logic, from bit to qubit (DL, 3 h)		Lecture, group worksheet, frontal teaching and individual work
3. The logic of quantum physics: one-qubit gates, two-qubit non entangling and entangling gates (DL, 6 h)	QuVis simulation, optical implementation of gates	Lecture and individual work
4. Classical and quantum algorithms (DL, 3 h)	Mach-Zender implementation of algorithms	Lecture, group worksheet, and individual work
5. Bell inequalities and quantum protocols (DL, 3 h)		Lecture, group worksheet, and individual work
6. Classical and quantum cryptography (DL, 1,5 h)	QuVis simulation	Lecture and individual work

Introduction to quantum theory and the physical problem of computation

In order to provide a consistent and comprehensive access point into the physical picture, the concepts, and the mathematical tools needed for tackling a course on quantum computation, we adopted and revised an educational proposal described in Pospiech et al. (2021), section 4. In our sequence, students are led to acquire respectively the notions of observable, quantum measurement, quantum state and state vector, superposition, quantum interference, entanglement of modes (spatial and spin modes) of a single system, and finally the entanglement of different systems. All of the topics above are examined both from a conceptual and mathematical perspective. The basic features of the quantum description emerge in a modelling activity specifically including epistemic practices of the theoretical physicist, first in the simple context of photon polarization and then in the scientifically significant contest of the hydrogen atom.

After introducing the main elements of quantum physics, students are stimulated to reflect on the profound link between classical physics, propositional logic and probability theory and to evaluate how these aspects can be reinterpreted in a different way in the light of the new behaviour of physical systems studied in the first part of the path. Such reflection paves the way for the introduction of a new logic capable of representing the encoding and manipulation of information in a way which is compatible with the structure of quantum mechanics. The point of arrival of this line of thought is a synthetic circuital representation of quantum processes which, as detailed in the following subsection, contributes to provide with intuitive, conceptual meaning the mathematical structure of quantum theory, and becomes the basic language of almost all the topics addressed in the following.

Educational reconstruction of quantum algorithms

Reasoning within the Model of Educational Reconstruction (MER; Duit et al., 2012), we argue that within the existing research on teaching-learning quantum technologies, and in the specific case of quantum computation, no sufficient attention has been given yet to the clarification and analysis of science subject matter, and in particular to the issue of elementarization. Within the MER, elementarization is the process by which the content matter is analysed with the objective of identifying the elementary features (basic phenomena, principles, laws) which may be said to be the cornerstones for explanation, and understanding, of the field. Thus, elementarizing is not "simplifying", but finding an underlying structure within the subject matter (sometimes, at the expense of some degree of acceptable actual simplification) which can function as scaffold and guide for the learning process.

Based on an analysis of algorithms are of educational relevance for introductory teaching (i.e. primarily the Deutsch and Grover algorithm) we proposed an elementarization of their working principles based on the different identification of three different operational functions that each algorithm has to enact in order to obtain the desired result: 1) the activation of quantum parallelism on input qubits by means of Hadamard gate(s), in order to have a state composed of a balanced superposition of all basis states, so that the oracle can act on all of them simultaneously, although concretely acting on a single physical system; quantum parallelism in essence stems from the possibly of quantum systems of being in a state of superposition of two (or more) basis states; 2) the transfer of information from the oracle to the transfer qubits; this operation modifies the input superposition, in some cases (the Grover algorithm) producing entangled states, in some others (the Dutsch algorithm with less than 3 qubits) not; and 3) the activation of interference to move towards the final output result of the algorithm, which results from the outcome of a measurement. One clarifying note should be added concerning the concept of quantum entanglement: there has been considerable debate among researchers in quantum technologies (Ding and Jin, 2007) on whether the presence of entanglement a necessary element for the explanation of the advantage of quantum over classical over quantum algorithms, or instead entanglement should be considered as an accessory concept, which bears no particular significance to quantum computation. There seems to be at the moment no consensus among researchers, and at the level of an educational reconstruction, the presence of an open research question understandable to students can be of educational and motivational value, as long as students are provided with appropriate instruments for actually grasping the issue. Thus, the concept of entanglement is introduced with students before the introduction of quantum algorithms (see the previous Section), and the existence of an open question is explained, but the full treatment including circuits capable of producing entangled states are delayed to the final part of the course. In the Data Analysis Section, we will discuss on whether such elementarization scheme has been successful in providing adequate scaffolding for students' learning process.

Final part of the sequence: Bell states, teleportation protocol, quantum cryptography

Already in the treatment of quantum algorithms, the introduction of the Mach-Zender interferometer represents the key to connect, one by one, the symbolic elements of the circuital language to physical devices, both those, introduced previously when dealing with polarization, and the ones related to the interferometer. In this way polarizers, birefringent crystals, beam-splitters, and phase delay plates play the role of clarifying to students the correspondence between a step of an algorithmic sequence, its representation in the diagrammatic language, and the properties of physical systems which allow, at least in principle, its realization. From a formal point of view, the course allows students to establish a connection between the algebraic manipulation of states using the Dirac notation and vector algebra and its visualization and conceptual representation through the diagrammatic-circuit approach. Such work opens the way for the introduction in the last part of the TLS of circuits describing Bell states, and to show the most interesting applications of entangled states in quantum protocols and quantum cryptography. The TLS makes use of both available research-based simulation such as QuVis (Paetkau and Kohlne, 2016) and some specially tailored for the present experimentation of our own design.

The first application of the TLS which we report on with this poster was performed with students who self-selected on the basis of special interest in the topics of modern physics. The experimentation should be intended as the first stage of a Design-Based Research (Barab, 2006) project, studying its general feasibility; the final goal is to produce and refine a TLS appropriate for general curricular teaching.

CONTEXT AND DATA COLLECTION

The experimentation involved initially 14 students of the 12th and 13th grade (17–19-year-old) of *Liceo Classico* (4) e *Liceo Scientifico* (10) Galilei - Grattoni di Voghera, self-selected through interest about the topic of quantum computation and information. In fact, the course was performed as part of a school experimentation in which a small part of the curricular courses could be chosen by students electively (unusual in the Italian system). In the Italian system, both *liceo classico* and *liceo scientifico* are types of secondary school attended by students who intend to continue their studies in university; *liceo classico* is more oriented towards literacy and human sciences (for example, it includes Greek) while *liceo scientifico* is more focused on STEM disciplines. Halfway into the course, school rules gave students the opportunity of choosing different courses, and the number of students reduced to 8, 6 of which from *liceo scientifico* and 2 from *liceo classico*. All activities were performed in distance learning because of COVID-19 limitations. Data collected during the teaching experiment includes pre-test. post-test, the laboratory sheets and reports, worksheets used by students for exercises and problems, the notes taken during the activities on students' comments, questions and difficulties.

RESULTS

Student engagement with the course

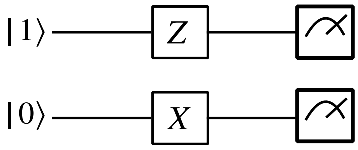
In general, students took part to the proposed activities with interest and a positive attitude. However, the fact itself that 6 students out of 14 switched courses after the first part is clearly an indication of lack of interest/engagement, at least for part of the students enrolled. From a global evaluation of experimentation data, it appears that most students leaving halfway in the course had difficulties with the mathematical/formal aspects of the course, which of course is not encouraging in a sample which was self-selected to start with. Future redesign of the course will have to take this element into account, as will be addressed in the conclusions. On the other hand, the remaining students seemed highly motivated and on par with the mathematical and conceptual requirements (see the following subsections), and at the end of the course most of them expressed the desire of delving even further into applicative aspects of quantum physics.

Understanding and connecting different representations of quantum processes

One of the intermediate worksheets we assigned to students consisted in a series of items probing the capabilities of students in a) translating circuital diagrams into Dirac and matrix notations, and using such notations to perform actual calculations; b) connecting the operations performed by logical gates to the graphical representation of quantum states; c) connecting the formal expression of a state to the probabilities of measurement outcomes. In the approach we adopted, the circuital representation of quantum algorithms played a crucial role in mediating between the mathematical machinery needed for calculations and the physical principles underlying the algorithms. The text of the worksheet is reported in Figure 2.

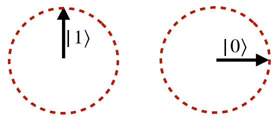
The work made for the construction of the qubit concept starting from polarization, and the subsequent interpretation of logic gates as axial symmetries in the state space seems to have been well understood by almost all students. Furthermore, the 6 students from *liceo scientifico* also solved, for the most part correctly, more demanding questions in terms of mathematical manipulations (mostly item 4), while students of *liceo classico* displayed difficulties in this sense, due to their more limited mathematical background.

Consider the following circuit:



1. Develop the two registers individually in both Dirac and matrix notation explaining, when measuring, which classical bits and with what probability are obtained on each register.

2. Represent the operations carried out algebraically on each register in the plane corresponding to it.



3. Consider the compound system $|10\rangle$ and evolve it in Dirac notation along the circuit. Imagine we make a measurement of the final state: what classical bits would we obtain? With what probability? Explain how the results were obtained.

4. Build the matrix $Z \otimes X$ and explain how it was obtained. Evolve the vector corresponding to the initial state $|10\rangle$ using the matrix obtained.

Figure 22. Problem on the connection between different representations of quantum processes given to students as intermediate worksheet.

Qualitative and conceptual understanding of quantum algorithms

In the final test we preferred to design questions that would allow us to evaluate whether the students had understood the conceptual aspects of the proposed topics, leaving the elements of pure algebraic calculation as optional. Here we report one of the two items related to the third design principle, the decomposition of quantum algorithms into three fundamental processes. To understand whether the proposed approach had supported the conceptual understanding of the Deutsch algorithm, the item asked to analyze the circuit by visually identifying the three processes and conceptually describing their structure, connecting their informational role with the physical principles underlying their action (See Figure 3). Another similar item was contained in the final test, concerning quantum teleportation.

Use Deutsch's algorithm to introduce the main elements of quantum algorithms: quantum parallelism, the role of the operator on target and ancilla, interference and measurement. For each of these elements, identify the parts of the circuit that represent them and identify which aspects of quantum physics are involved. (If you think it is necessary, carry out some calculations)

Figure 3. Final test exercise on the Deutsch algorithm.

We conducted a qualitative analysis of the answers to the final test aimed at determining whether the division in subprocesses we provided students with had been productive for their learning. All students were able to correctly highlight, in the circuital representation of Deutsch's algorithm, the portions of circuit corresponding to each of the three significant subprocesses (the enabling of quantum parallelism, the transfer of information from the oracle to the ancilla and target, the final selection of the result). All students also identified, at least partially, the links between each subprocess and individual features of quantum physical behavior and description, such as quantum superposition, the multiplicative structure of quantum compound systems which allows a phase factor to be considered related indifferently to the target or ancilla, quantum interference. Some students supported their reasoning with explicit calculations, but only as a complement to the considerations made earlier, so that they don't seem to rely solely on mathematics for sense-making. The similarly structured question which was given on the teleportation protocol produced comparable results. By examining students' answers, we can conclude that the elementarization we performed of the internal transformations from input to output within a quantum algorithm was successful in scaffolding students' learning process and providing a general framework to imbue such transformations with conceptual meaning.

CONCLUSIONS

The analysis of the experimentation data on one hand gives us a globally positive feedback on our basic inquiry about the feasibility of the path described with 17-19 year old students, providing encouraging indications on both the sides of conceptual understanding and learning engagement. On the other hand, the fact that 6 out of 14 students chose not to continue with the course after the first part is a strong element of warning, indicating that possibly our strategies for sustaining engagement and interest were not effective for all students, and/or further work is needed to reduce the impact on students' cognitive resources required with the introduction of new mathematical and formal tools. A mitigating consideration may be that the distance teaching/learning process makes it very difficult to promptly address individual difficulties of students; Data also show rich and complex learning patterns, allowing to uncover peculiar reasoning paths and cognitive strategies of students, and to identify which activities may be more productive for students and which ones may show weak points and lead to student difficulties. Future redesign of the course for fully curricular use will have to take into account 1) a more gradual introduction of the mathematical tools needed for analysis of quantum circuits, 2) further enrichment of the interdisciplinary and intra-disciplinary character of the sequence in order to "activate" students with different areas of interest and reinforce knowledge integration. Among the other future directions on which we are currently working we mention:

- The realization of an experimental implementation of the Deutsch and Grover algorithms with macroscopic light beams on the optical bench. In fact, the mathematical identity between the classical and quantum approach to the dual rail allows in principle to run such algorithms with classical polarized light sources, interpreting the relative intensity of light collected at different detectors in probabilistic terms.
- The development of an interactive computer simulation connecting the circuital representation of educationally relevant quantum algorithms and protocols to their possible physical realization using optical elements.

  Both the tools above described are meant to be used in the context of inquiry activities for small student groups, in such a way as to encourage the social construction of knowledge and reinforce the connection between physical reality, the diagrammatic and graphical tools used, and the mathematical model.

REFERENCES

Barab, S. (2006). Design-based research. The Cambridge handbook of the learning sciences, 153-169.

Ding, S., & Jin, Z. (2007). Review on the study of entanglement in quantum computation speedup. Chinese Science Bulletin, 52(16), 2161-2166.

Duit, R., Gropengiesser, H., Kattmann, U., Komorek, M. and Parchmann, I. (2012), “The model of educational reconstruction - a framework for improving teaching and learning science,” in Science Education Research and Practice in Europe, edited by D. Jorde and J. Dillon (SENSE Publishers, Rotterdam, The Netherlands), pp. 13–37.

European Quantum Flagship (2020, February). Strategic Research Agenda. https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=65402

Feynman, R. P. (1982). Simulating physics with computers. Int. J. Theor. Phys, 21(6/7).

Isham, C. J. (2001). Lectures on quantum theory Mathematical and structural foundations. Allied Publishers.

Malgieri, M., Branchetti, L., De Ambrosis, A., Levrini, O., and Tasquier, G. (2017, August). Students’ idiosyncratic voices and the learning of quantum physics in secondary school: a case study of Appropriation. In ESERA Conference, 21-25 August, Dublin.

MIUR – Ministero dell’Istruzione, dell’Università e della Ricerca. Indicazioni Nazionali per i Licei (2012) https://www.istruzione.it/alternanza/allegati/NORMATIVA%20ASL/INDICAZIONI%20NAZIONALI%20PER%20I%20LICEI.pdf

Paetkau, M., & Kohnle, A. (2016). Development, Testing and Efficacy of QuVis Simulations. Bulletin of the American Physical Society, 61.

Pospiech, G., Merzel, A., Zuccarini, G., Weissman, E., Katz, N., Galili, I., ... & Michelini, M. (2021). The Role of Mathematics in Teaching Quantum Physics at High School. In *Teaching-Learning Contemporary Physics* (pp. 47-70). Springer, Cham.