Proceedings INTED2019 conference Valencia, Spain doi: 10.21125/inted.2019.1233

THE EDU-ARCTIC PROJECT: INTERACTING FOR STEM ACROSS COUNTRIES AND CURRICULA

P.E. Aspholm[1], F.J. Gómez Senent[2], H.K. Wam[1], A. Goździk[3]

[1]*Norwegian Institute of Bioeconomy Research (NORWAY)*
[2]*Instituto de Educación Secundaria IES THÁDER (SPAIN)*
[3]*Institute of Geophysics, Polish Academy of Sciences (POLAND)*

Abstract

EDU-ARCTIC is an open-schooling project, funded by the EU for the years 2016-2019 and managed by scientists, nature educators and computer–technologists. The main aim is to attract young people (13-20 years old) to the natural sciences. Further, to raise awareness of how everything in nature is connected, and that STEM education therefore in part must be interdisciplinary across normal school curricula. To achieve these goals, EDU-ARCTIC uses innovative online and freely accessible tools, combined with nature expeditions.

Four main modules complement each other, but can also be used independently:
1) Webinars, during which scientists conduct online lessons about their own field of expertise. The lessons come as packages with worksheets and online games. The lessons bring youth close to scientists. They can ask questions about research and conditions of scientific works. It is also a valuable tool for teachers to brush up their STEM knowledge and get inspiration for their own teaching.
2) Polarpedia, which is an online encyclopedia of scientific terms used in the webinars. The science is kept easy-to-grasp, with the aim to stimulate the pupils' curiosity to look for more information.
3) Monitoring system, which uses citizen science and the project's own app to record observations of meteorology and phenology. Observations are open for everybody to use in their own teachings.
4) Arctic Competitions, which is the module that has engaged the pupils the most. They submit their idea for a science project in winter, work with the project over a few months and present it in spring as an essay, a poster or a video. Teachers come up with innovative ways to fit this work into the normal curricula. A few lucky winners get to join scientists on expeditions to polar research stations.

After 2.5 years, EDU-ARCTIC has engaged more than 1100 teachers and educators from 58 countries. There is a language barrier for some teachers, and it is difficult to fit webinars into the school timetable. However, the challenges are minor compared to the interdisciplinary success of having teachers meet across countries and curricula. Here we illustrate this in detail by presenting a way of interdisciplinary teaching ("the beauty of poetry and maths") developed by one of the teachers in the project, Mr. Francisco José Gómez Senent. Starting from a single poem published in Nature, it innovatively combines mathematics, literature, history and linguistic competences. The teacher originally used it to stimulate curiosity about the aesthetic criterion in science. Science is not only about facts! The approach can be generalized to cover a wide range of curricula, and different teachers can use it in a team effort across classes.

Conclusion: The EDU-ARCTIC project has demonstrated that letting teachers meet across countries and teaching fields facilitates inspiring and innovative cross-overs in the normal school curricula. When teachers are inspired we believe it creates a happy teacher – happy teaching effect

trans-disciplinarily understanding

1 INTRODUCTION

There is a need for development of more interdisciplinary (or transdisciplinary) approaches to education in order to meet increasingly interrelating societies. Opportunities, actions and concerns are no longer isolated within communities and national boundaries, but flows freely largely due to the global internet. With this transcendence of geographic and cultural borders, also comes the transcendence of skills and knowledge. The Report of the European Commission (EC) – *Science Education for Responsible Citizenship* [1] emphasize that science education is vital to develop a culture of responsible thinking and evidence-based reasoning for sustainable decision making. Because today's youth are tomorrow's decision makers, it is particularly important that young people engage in issues on environmental and social sustainability.

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2 METHODOLOGY & RESULTS

2.1 The interdisciplinary teaching elements of EDU-ARCTIC

There are four teaching modules in EDU-ARCTIC, and they are all freely available on the web portal (https://program.edu-arctic.eu/). We built modules with the specific aim of interdisciplinary exchanges and outcomes. Therefore each module comprises topics from the whole range of school STEM curricula, with emphasize on the natural sciences of biology and physics, but due to the interdisciplinary aim we also used art, social sciences and engineering. For a given element within a module (i.e. one webinar, one Polarpedia term etc.), we encouraged the scientists in charge to place their topic into a broader context of societal and environmental issues. The four modules complement each other topically and methodologically, but can also be used independently.

1) Webinars, where scientists conduct online lessons about their own field of expertise. The lessons comes as packages with worksheets and online games. The lessons brings youth close to scientists. They can ask questions about scientific careers and condition of research work. It is also a valuable tool for teachers to brush up their knowledge and get inspiration for their own teaching. Webinars are conducted in English, and also other European languages upon request from a sufficient number of teachers. From January 2017 to December 2018 EDU-ARCTIC made over 400 webinars (of which 171 were unique topics). Some were given in more languages and some were repeated. The webinars were enrolled by 7 073 teachers (4 552 actually participated) with varying numbers of pupils in their classes.

2) Polarpedia, which is an evolving online encyclopedia of scientific terms used in the webinars. The science is kept easy-to-grasp, with the aim to stimulate the pupils' curiosity to look for more information. The Polarpedia supplements the webinars, and can be used to prepare for the webinars. Terms are elaborated in English, and translated to several other European languages (up to 15 for the most used terms). As per January 2019, EDU-ARCTIC has prepared 429 Polarpedia terms. They are organized in nine categories: Ice & Snow, Climate & Weather, People & Society, Atmosphere, Animals & Plants, Water resources, Land & Geology, Space and Places & Stories. Moreover, additional part of Polarpedia contains educational resources to be used by teachers and students in form of online games, quizzes, worksheets, experiments, teamwork proposals and other. The Games & Quizzes section consist of 88 various resources (as per January 2019) and is still growing.

3) Monitoring system, which uses citizen science and the project's own computer, table or cell phone app to record observations of meteorology and phenology. For example, when certain bird species are first observed in spring, or what the temperature is at a given date and time throughout Europe. Observations are open for everybody to use in their own teachings.

4) Arctic Competitions, which is the module that has engaged *the pupils* the most. They submit their idea for a science project in winter, work with the project over a few months and present it in spring as an essay, a poster or a video. Teachers come up with innovative ways to fit this work into the normal curricula. A few lucky winners get to join scientists on expeditions to polar research stations.

In addition, we have carried out on-site and hands-on workshops (Oslo, Warsaw and Paris) to give teachers a meeting place for exchanging ideas on how to use EDU-ARCTIC resources interdisciplinary in the classroom, and to become ambassadors of the project in their home countries.

2.2 Poetry and Mathematics, a teacher's case in point

One of the main attractions of the EDU-ARCTIC project is the possibility that it offers teachers and students to integrate knowledge from different subjects. In addition, the Arctic suggests a virtually virgin world in which the beauty of its nature can especially motivate the interest of students. These two aspects, the interdisciplinary and the development of aesthetic criteria in scientific work, can be taken as part of the essential objectives of the teaching process.

As a case in point, these objectives can be approached by introducing the scientific literature in the classes as part of the learning of the subject. The simplest way is to use texts that provide context and culture on the subject being studied, but when possible, we could try to make reading a starting point to extend the scope of the topic so that the student can grasp the matter as part of a whole that includes different areas.

2.2.1 Proposal of the activity to the students

This work proposal is aimed at Secondary school and its main objective is the possibility of using the linguistic analysis of a poem with mathematical content (in addition, on a non-elementary result) to convey to the students the aesthetic criterion that mathematicians (and scientists in general) use in a very important way when solving a problem, proving a theorem or building a theoretical model.

On this question there is no doubt in the mathematical community, which can be illustrated quite bluntly with the well-known quote by Karl Weierstrass:

> *"A mathematician who is not in some sense a poet, will never be a complete mathematician".*

Thus, the central idea of this proposal is to analyse a real and important case of symbiosis between two branches, Poetry and Mathematics, as it shows to students that Mathematics is present in more areas than they perceive. To do this, they will consider, based on the content of the poem, some interdisciplinary activities that would allow teachers of different subjects to transmit to the students the fact that one can work on the same interconnected thematic axis, expanding in the different subjects, so that they assume that all knowledge is related and it is not part of separated areas.

The poem in which we focus the entire didactic proposal is the following:

The Kiss Precise

For pairs of lips to kiss maybe
involves no trigonometry.
'Tis not so when four circles kiss
each one the other three.
To bring this off the four must be
as three in one or one in three.
If one in three, beyond a doubt
each gets three kisses from without.
If three in one, then is that one
thrice kissed internally.

Four circles to the kissing come.
The smaller are the benter.
The bend is just the inverse of
the distance from the centre.
Though their intrigue left Euclid dumb
there's now no need for rule of thumb.
Since zero bend's a dead straight line
and concave bends have minus sign,
the sum of the squares of all four bends
is half the square of their sum.

To spy out spherical affairs
an oscular surveyor
might find the task laborious,
the sphere is much the gayer,
and now besides the pair of pairs
a fifth sphere in the kissing shares.
Yet, signs and zero as before,
for each to kiss the other four
the square of the sum of all five bends
is thrice the sum of their squares.

Frederick Soddy, Nature 137 (June/20/1936, DOI 10.1038/1371021a0)

We will suggest to the students the tasks summarized below, structured from the essential point of view of working in an *interdisciplinary* way. First, we will analyze the linguistic and mathematical content of poetry. Simply by its presentation, it is already achieved to a large extent that the student perceives the importance of the *aesthetic criterion* as a basis for debugging the proof of a theorem. Then we will continue by specifying some activities that allow us to broaden the scope of discussion, not centered on poetry, but connected in some way with it. It is intended that students investigate, seek information and consult several teachers.

The proposed tasks are: (a) Translate the poem into their native language. (b) Analyze which are the main ideas of the poem and the order in which they are presented, discussing its structural similarity compared to the way in which a mathematical theorem is exposed. (c) Make a text comment on the poem following the model that is explained in literature class. (d) Express the formula of the thesis of the poem. (e) Document the history of this problem and summarize your impressions. (f) Investigate about similar problems. (g) Thinking about the generalization to *n* dimensions, with the extension of the

 doi: 10.21125/inted.2019.1233

poem by Thorold Gosset in *Nature*, January 1937. (h) Comment about the poetic format in the presentation of this result in *Nature*. (i) Biography of Frederick Soddy. (j) Solve the problem by using technical drawing tools, analyzing what mathematical contents of synthetic geometry are used. (k) Implement the solution with *GeoGebra*, by admitting that the 3 initial circles are not tangent, allowing to modify the parameters of the graphics, in order to show numerically the theorem.

The method of work would consist in posing the tasks giving enough time to the students to solve them at home; then, at least two sessions of lectures would be devoted to discuss the fundamental aspects, exchange opinions and solve the doubts that would surely arise. What is intended with this wide range of activities is to present multiple possibilities, in such a way that each student can work according to their interests, only with some of the questions.

The essence for the development of this experience consists of the *text commentary*, the fact that the students perceive the meaning of the *aesthetics* present in scientific research, and that clearly *visualize* the solution to the problem, presented also with the *GeoGebra* mathematical software.

2.2.2 Keys for interdisciplinary sharing in the classroom

Some key concepts that should be discussed in the sharing between students in the classroom are:

- Some difficulties in the translation of the poem to another language, because original wording is specific for the poetic language. It is possible to create confusion with an ambiguous translation, and even the reader might not understand the fact that the problem in the plane is becoming generalized to space in the last stanza. The student will be able to grasp with this activity the importance that the *rigor of the language* acquires in any scientific area.

- The thematic axis consists of communicating the beauty of this geometric result. But the author chooses the poetic form to express with greater emphasis and intensity the scientific result, in such a way that the dominant linguistic function is poetic, characterized by the metaphor of circles (spheres) that kiss, praising the image of beauty that has the problem. And they do it *precisely*, as the title says, symbolizing the rigorously established tangencies according to the numerical relationship.

- Regarding the text comment, we point out here some ideas, since this is not a usual activity in science class. As for the *cohesion* of the text, firstly, the grammatical connection that is achieved through constant repetition of some words related to several semantic fields, are examples of the concept of isotopy that make possible a uniform reading of the text. About to the morphosyntactic resources used to articulate the poem, we have to mention the use of the present and the infinitive, with a timeless sense, to emphasize that what is stated (mathematical law) has a universal scope. Also, the frequent use of markers or discursive connectors, deictic elements, and constructions with a cataphoric or anaphoric sense reinforce the cohesion of the text.

Moreover, the *coherence* is the textual property, basically semantic, which indicates what is the relevant information to be communicated and how it should be done. Except for the pertinent love rhetoric to enhance the beauty of the geometric situation, Soddy is limited to schematizing the statement of the problem, expose the essential definition of curvature without giving it as previously known, and enunciate the thesis of the theorem. And in the last stanza it only points out that now there are five spheres and it states the generalized thesis. So, it is very remarkable that the structure of the text follows closely the standard pattern of the mathematical exposition: approach of the problem, hypothesis, definitions, particular observations, and thesis. All this progressively develops in the first two stanzas, from the initial approach to the outcome (thesis of the theorem) in verses 19-20.

- Does the text achieve its communicative purpose? The author only uses the essential specialized terms (*curvature*, *concave*) that the problem requires; likewise, he adjusts the message, its language and its form taking into account the medium in which it was published and its lack of orthodoxy regarding the *status quo* of the form of scientific communication commonly admitted. In linguistic terms, the text reaches a remarkable degree of *adequacy*.

- The formula for *n* dimensions is:

$$\left(C_1 + C_2 + C_3 + ... + C_{n+2}\right)^2 = n \cdot \left(C_1^2 + C_2^2 + C_3^2 + ... + C_{n+2}^2\right) \quad \text{where} \quad C_k = 1/R_k$$

The most interesting comments about it refer to the symmetry it presents in any dimension, depending on the value of *n* itself. On the other hand, the activity arises to give rise to the debate on the work of mathematicians in *n* dimensions, not visualizable but algebraically equal for them that the usual 3 of the space: the students are surprised by the ease with which a mathematician gives the dimensional jump

 doi: 10.21125/inted.2019.1233

(it can be captured clearly in Gosset's poem), while it is impossible for them to imagine anything, although they are very interested in 3D shadows of figures such as Klein's bottle, which can be presented to them in this activity.

- When the students document the history of the problem (which include Apollonius, Euclid and Descartes), and seek information about *Nature* or Soddy, they enter the History of Science from an interdisciplinary point of view, knowing the importance and the role of scientific journals and that Soddy was awarded the Nobel Prize in Chemistry. Moreover, the fact that at the end of his main research work was devoted to studying mathematical problems, will give rise to comment on the vision of mathematics as fun, at least for some.

- An approximate sketch of the geometric situation will be done by any student. But if you want accuracy, only some students, and with the help of the corresponding teacher, will be able, since the mathematical concepts of investment, power of a point, axis and radical center appear.

- The teacher can show in class the possibilities of dynamic geometry with *GeoGebra*, and visualize the real poetry and beauty in motion of the problem, while the live modification of the radios will allow students understand how a numerical, empirical demonstration, can be made in the current computer age. In some way, they will be experimenting in the "computer lab" of Mathematics. Next we show in Fig. 1 an image of the solution of the problem made with *Geogebra* by the author of this proposal.

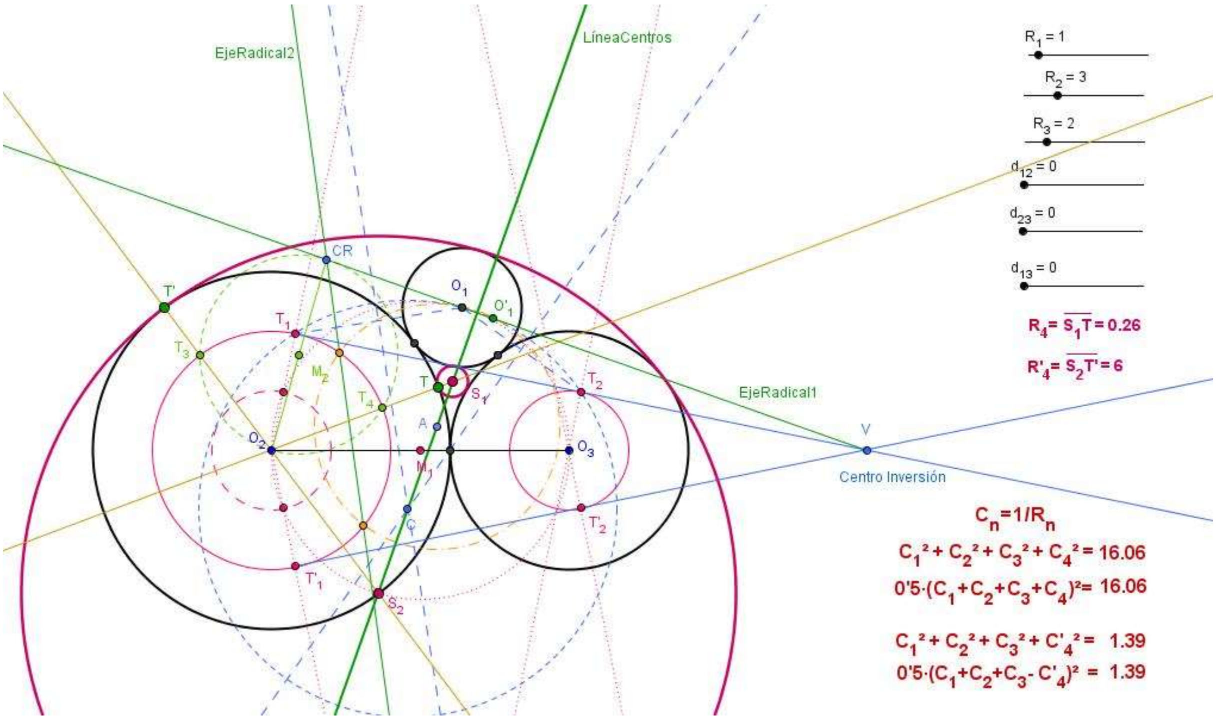

Figure 1. Empirical verification of the theorem of the 4 circles, with GeoGebra. Soddy showed that there is an elegant relationship (expressed in the image) between the curvatures of 3 given circumferences tangent to each other, and the 2 new circumferences tangent to these 3 that can be built, as Apollonius and Descartes had proved.

2.2.3 Experiences from the classroom

The ideas outlined above in the previous section, come in part from the answers provided by the author's own students who has been engaged in the proposed activities. More details and extension on the results of the activity, can be consulted in [3].

Mainly, they highlight the perfect parallelism between the mathematical theory of the two theorems that are exposed, and the literary discourse that is made. In addition, they are able to solve the problem graphically with different methods, by using several mathematical concepts.

Also, it is remarkable that they get some translations better than the known one published in Spanish or the one posed by the teacher, showing the depth which they have dedicated themselves to understanding the problem. Finally, at the end of the experience, the students become interested in the history of science and appreciate the importance of acquiring a minimum of scientific culture.

But above all, they comment on the surprise they experience about the many types of tasks that arises from “simply a poem”, which are so different from the usual work in science! In summary, from *interdisciplinary* work the student will grasp the presence and *beauty* of Mathematics. The goal is to get excited about science, and with this activity it is achieved.

3 CONCLUSIONS

First, let us be honest about the challenges: The interdisciplinary compilation of EDU-ARCTIC comprises a logistic challenge for teachers, who are more or less obliged to cover very specific curricula within a very specific timeframe. Incorporating the EDU-ARCTIC modules therefore has worked the best for teachers who are able to be fairly flexible about their teaching and schedules. This particularly – and generally – applies to *live streamed* teaching resources. This has long been acknowledged in the literature on online teaching [4], and as such must be considered a challenge likely to persist into the future. We emphasize the value of providing teachers with alternative ways to access live resources. In EDU-ARCTIC, we have achieved this by scheduling multiple versions of the most popular webinars, and by making recordings of the webinars available through the project YouTube channel.

Despite these inherent challenges, the interdisciplinary compilation of EDU-ARCTIC teaching modules appear to have provided a stimulating environment for teachers to broaden and rethink their approaches to teaching. We have yet to compile our systematic statistics on the teachers’ experiences and summarise the evaluation results, which may be an object of another publication. However, even on this stage of the project’s implementation and o the bases of on-going evaluation of the EDU-ARCTIC modules, we observe that teachers declare that the proposed activities have positive impact on both: students’ interest in STEM and an increase of the level of their knowledge about polar regions and various environmental issues related to the Arctic.

From a teacher’s view: “In my attempt to present mathematics in an interdisciplinary way, I have been using novels and other literary texts for many years, such as the poem presented here, but also photographs, artistic works, films or small Youtube videos. In all this approach I try to relate mathematics to the humanities, the arts and everyday life, as well as to the sciences. But the resources of EDU-ARCTIC now provide me with new texts, videos or webinars that are very useful to relate mathematics to other sciences from a practical point of view. For example, you can start with a term from the Polarpedia and follow a thread of research through a video or webinar to learn about a specific topic, so that later search for more information on the web, initiating the student in the research work. Finally, I suggest to the most interested students, small research projects that oblige them to go deeper into some way in applied mathematics. In these two years, we have focused on climate problems, but we will try to broaden the focus in the future. In any case, the attraction that the Arctic provokes and the possibility of raising real research with real data in the Arctic Competition motivates the students, and myself, more than any other activity that I have previously done with students”. – *Francisco José Gómez Senent*

In summary, the EDU-ARCTIC project has demonstrated that letting teachers meet across countries and teaching fields facilitates inspiring and innovative cross-overs in the normal school curricula. When teachers are inspired we believe it creates a happy teacher – happy learning effect [5].

ACKNOWLEDGEMENTS

EDU-ARCTIC project has received funding from the European Union’s Horizon 2020 research and innovation program under grant agreement No 710240.All the EDU-ARCTIC consortium contributed to the work from which this paper was created. We wish to acknowledge specifically: Anna Wielgopolan, Krzysztof Man, Piotr Głowacki, Lis Mortensen, Barbara Biskopstø Hansen, Gunnleyg Ihlen, Halldór Jóhannsson, Grzegorz Bunia, Tomasz Juńczyk, Fanney Sigrún Ingvadóttir and Jan Borm.

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