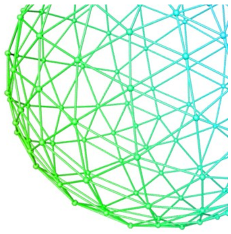
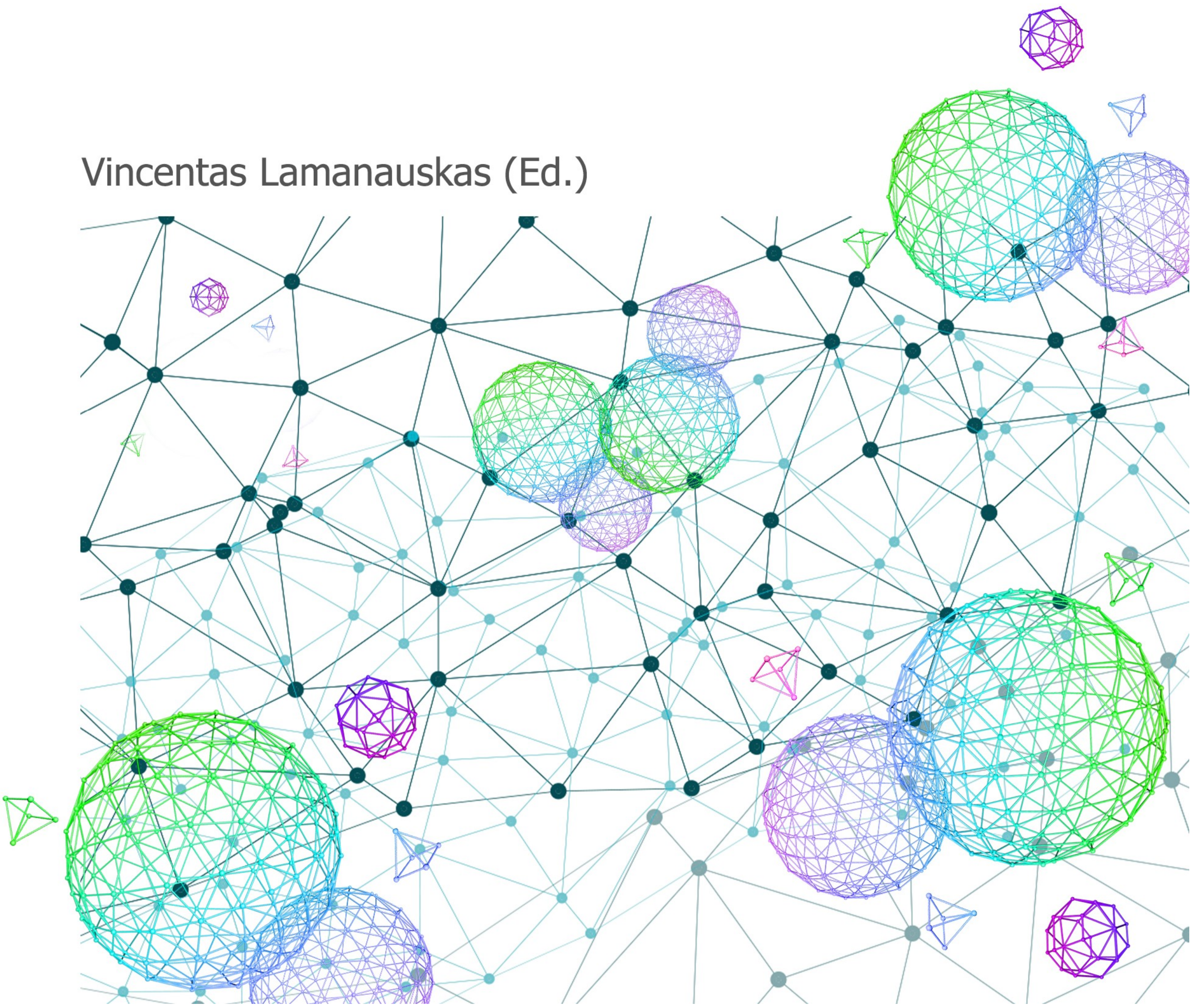


SCIENCE AND TECHNOLOGY EDUCATION: DEVELOPING A GLOBAL PERSPECTIVE

Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021),
Šiauliai, 21–22 June, 2021

Vincentas Lamanauskas (Ed.)



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SCIENTIA SOCIALIS

Šiauliai, 2021

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ISBN 978-609-95513-7-1 /Print/, ISBN 978-609-95513-8-8 /Online/
DOI: 10.33225/BalticSTE/2021

All articles of this symposium proceedings are indexed in the Academic Resource Index (ResearchBib), CEEOL (Central and Eastern European Online Library), Internet Archive, Scribd, Crossref, DOI

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ISBN 978-609-95513-7-1 /Print/
ISBN 978-609-95513-8-8 /Online/

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THE METHODOLOGY FOR CREATING WORKSHEETS FOR INTEGRATED SCIENCE

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Abstract

Integrated teaching is teaching in which the educational contents of subjects are interconnected. Connections can be discussed in a specialized integrated subjects e.g., Integrated science. Integrated science is a subject that connects knowledge from chemistry, biology, physics, geography, and geology. One topic is discussed from a different point of view, and students should transform their theoretical knowledge in practice. Worksheets can serve as a teaching material that can provide help to students as well as teachers and guide students on their path to knowledge. But how should a worksheet look like and how should the tasks be designed? This contribution describes a suggested method for making a worksheet for integrated (science) teaching that we call CCCTER. CCCTER is abbreviation for choose, connect, create, try, evaluate, remade. The method implements the national Framework education program for secondary general education (grammar schools) in the process of making the tasks. The principles choose, connect, and create are demonstrated. It provides a sample task of a worksheet for integrated (science) teaching.
Keywords: *methodology for creating worksheets, integrated science, integrated teaching*

Introduction

Integrated teaching is a term that is not firmly entrenched in the literature. In our research we define integrated teaching as teaching in which the educational contents of subjects are interconnected "while the integrated educational content follows the aims of all integrated subjects. At the same time, a new aim is formed, which results from the integrated whole" (Rakoušová, 2008, p. 15). "It implements interdisciplinary relationships and a connection between theoretical and practical activities" (Průcha et al., 2001, p. 87). We perceive integrated teaching as The Integrated Model from publication Ten ways to Integrate Curriculum written by Robin Fogarty (1991). In this publication in The Integrated Model "interdisciplinary topics are rearranged around overlapping concepts and emergent patterns and designs. The integration sprouts from within the various disciplines, and teachers make matches among them as commonalities emerge" (Fogarty, 1991, p. 64).

https://doi.org/10.33225/BalticSTE/2021.07

According to the research made in 2020 in the Moravian-Silesian region of the Czech Republic (Bartoňová & Kričfaluši, 2020) a total of 66,4 % of secondary school teachers, that were part of the survey, think that they do include integrated teaching into their lessons. The second most common way of doing it was by modules or topics that are included as a part of more subjects. A total of 33.6 % of respondents think that they do not include integrated teaching into their lessons and the third most common reason for that is (according to the respondents) lack of didactic materials. Also, the research shows that the teachers may not understand the term integrated teaching correctly and most probably confused it with inter-subjects' relations. Further research is needed to confirm that.

As well as integrated teaching a worksheet is hard to define by one source. One definition is that "a worksheet is a set of tasks, exercises, didactic image material etc., that usually serves to independent student practice or provides him with a guide to his work" (Čapek, 2015, p. 124). The Cambridge dictionary defines a worksheet as "a piece of paper with questions and exercises for students". Another perspective is that "a worksheet is a piece of paper, a computer screen, or a projection that contains problems. These problems have right and wrong answers, and there is generally only one way to complete a problem" (Ransom & Manning, 2013, p. 188). Worksheets "include activities which give the students main responsibility in their own learning" (Yildirim et al., 2011, p. 45). Furthermore, according to Kurt (Atasoy et al., 2011) the worksheets "are very useful to observe and obtain results, can provide opportunity to reach new knowledge by way of student's own efforts, allow students to form hypothesis and do observation and experiment about a subject, help teachers to understand students' cognitive framework, can promote learning by doing and living, and keep students on task and make the learning fun" (p. 657).

Another point of view is that "worksheet serves to facilitate student's understanding in learning material by minimizing the role of teachers" (Nurrohmahadita, 2018, p. 142). In a pedagogical dictionary a worksheet is not defined but a workbook is. A workbook is defined as "a type of *cvičebnice*". *Cvičebnice* is defined as "type of textbook, the purpose of which is to repeat, consolidate certain knowledge, skills, creating habits etc." (Průcha et al., 2001, pp. 174 & 31). According to Ransom and Manning (2013) „the workbook is usually just a collection of worksheets with a glue on the spine" (p. 188).

A worksheet is a type of teaching material. Teaching material is "material or content that must be mastered by students through learning activities in accordance with the desired curriculum, arranged systematically, both written and not so as to create an environment or atmosphere that allows students to learn" (Fajriah & Suryaningsih, 2020, p. 1).

According to research (Podolak & Danforth, 2013) students favour the worksheets over textbooks and homework in a Modern Physics course. The research of Sulistiyowati et al. shows that "the application of STEM-based worksheet could effectively increase the science literacy" (Sulistiyowati et al., 2018, p. 89). Students' worksheets for integrated science were made for example by Widodo et al. for issues about motion in humans. The worksheets integrate students' knowledge about biology, physics, and chemistry. Students must integrate that knowledge to solve the problem (Widodo et al., 2018).

"Integrated science lesson is a natural science study whose study materials include biology, physics and chemistry as a whole" (Widodo et al., 2018, p. 2). The purpose of

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that lessons is "to enable learners to connect the concepts contained in the three different disciplines and apply them in the real world experienced by learners in their daily lives" (Widodo et al., 2018, p. 2).

Authors define integrated science lessons as lessons that connect knowledge from chemistry, biology, physics, geography, and geology. In those lessons the students think about a topic from a different point of view – as a chemist, biologist, physicist, geologist, geographer. They should be as close to the real life as possible, and students should verify their theoretical knowledge in practice.

Since one of the reasons for not implementing integrated teaching into lessons is the lack of materials, we decided to make the teaching material (worksheets in particular) that teachers may use in their integrated (science) lessons. The question is how should a worksheet be designed?

In the first steps of creating a worksheet for integrated science that is discussed further, a mind map is a useful tool. By a mind map is meant "activities that work with associations" (Čapek, 2015, p. 333). "Mind mapping allows students to imagine and explore associations between concepts" (Davies, 2010, p. 280). One of the advantages of mind mapping is that it "promotes creative thinking" (Davies, 2010, p. 282). On the other hand, "types of links being made are limited to simple associations" (Davies, 2010, p. 282). When we want to make more complex connections, we may use concept maps.

Methodology for Creating Worksheets for Integrated Science

The content of worksheets must be based on the national Framework education program (hereinafter referred as FEP) for secondary general education (grammar schools). A method "CCCTER" that stands for "choose, connect (FEP with tasks and theory with practice), create, try, evaluate, remade" is a suitable method for creating worksheets for Integrated science and is further described.

The worksheet tasks were created by following these steps (choose and connect)

1) First, we chose one topic that is learned in chemistry. Five subtopics were chosen, each subtopic is a theme of one of the worksheets. Then we thought about how to teach each subtopic by integrated science teaching based on our experience as teachers. A suitable way of doing that was a mind map or a concept map.
2) In that in mind the expected outcomes of all subjects of educational area Man and Nature (that includes the following subjects: chemistry, biology, physics, geography, geology) as well as of the cross-curricular subject Environmental education, that could be connected to the topic, were chosen.
3) In phase three the chosen expected outcomes were connected to the tasks that aim to meet the given expected outcome or more expected outcomes. At least one of the tasks must connect theory with practice.

All worksheets are created according to the following criteria (create)

1) Each task of a worksheet must be connected to at least one expected outcome from all subjects in the educational area Man and Nature.
2) Each worksheet must contain at least five tasks. Each task is connected at least to one of the subjects of educational area Man and Nature (the tasks can be interdisciplinary).

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3) Each worksheet must include laboratory work that can be inquiry based.
4) Each worksheet must contain such tasks in which there is a practical use of inter subject relations and context.
5) Each worksheet must respect active learning and activating methods of teaching because activating methods of teaching "enable the synthesis of the findings from various subjects and their usage in practical or didactically modified tasks or situations in a unique way" (Nováková, 2014, p. 5).
6) Each worksheet must contain different types of tasks from Tollingers' taxonomy.
    a. Tasks requiring memorable reproduction of knowledge e.g., *what is the weight of…* (Švec et al., 1996, p. 55)
    b. Tasks requiring simple cognitive operations with knowledge e.g., *determine the weight of…* (Švec et al., 1996, p. 56)
    c. Tasks requiring complex cognitive operations with knowledge e.g., *make a scheme of…* (Švec et al., 1996, p. 56)
    d. Task requiring transmission of knowledge e.g., *write brief content of…* (Švec et al., 1996, p. 57)
    e. Task requiring creative thinking e.g., *prove that…* (Švec et al., 1996, p. 57)

After the worksheets were created, the following steps proceed (try, evaluate, remade).

1) Worksheets were given a try in class with a sample of students. The feedback from students was given.
2) Worksheets were given to the experienced teachers for evaluation. The feedback was provided by an interview.
3) The feedback was processed and evaluated.
4) Worksheets were remade to be more suitable for students as well as for teachers.
5) The process of try, evaluate and remade can be repeated as many times as necessary.

Outcome

The example of choose, connect, and create put into practice is given.

Phase one - choose

First, one topic that is learned in chemistry was chosen – Halogens. Then authors reflected about their experience as teachers and thought about how this topic can be taught by integrated science learning. A mind map was made (see Figure 1 part 1 and part 2). As shown in the mind map, several connections among subjects can be made. For example, when teaching about yperite teachers can combine history (World War I) with chemistry (chemical compound) and biology (physiological effects) as well as with geography (Ypres, Belgium). Polyvinyl chloride can be thought from a chemist's perspective (chemical compound, polymer) as well as ecologist's (environmental pollution and sustainability). Sodium chloride is an important chemical compound (chemistry) with specific properties (physics), that plays an important role in our body (biology) and is an important component of The Dead Sea (geography). That is why topic Halogens is suitable for integrated lesson.

From the mind map five subtopics emerged. The subtopics were named as Halogens and plastics, Halogens and the ozone layer, Halogens and their cycle, Halogens and We, Halogens and their structure. After several discussions there was a need to "unchemistry" them in their titles so they will be judged by their content and not through their titles. New titles of the subtopics were Plastics, Ozone layer, Chlorines' cycle, Halogens in our hands, and Look for structure behind everything.

Phase two - connect

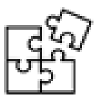
The expected outcomes of all subjects of educational area Man and Nature as well as of the cross-curricular subject Environmental education, that could be connected to these subtopics were chosen and connected with the tasks. An example is given on the following task that is part of a subtopic Plastics.

Expected outcome – Physics: The pupil shall distinguish between scalar and vector quantities and employ them while solving physical problems and exercises (Research Institute of Education in Prague, 2007, p. 27).

Expected outcome – Chemistry: The pupil shall characterise the basic groups of organic compounds and their significant representatives, evaluate their raw material sources, their application in practice and their effect on the environment (Research Institute of Education in Prague, 2007, p. 30).

Phase three - create

The task introduction:



One of the ways to dispose of PVC is to burn it. By burning PVC, energy is obtained. Its calorific value is 22.5 MJ per kilogram. Calorific value is a property of fuel that indicates how much energy is released by completely burning one unit, which is usually kg. By burning one kilogram of PVC, we get energy of 22.5 MJ. This energy can be converted to kWh according to the relation $1\ J = 2{,}778 \cdot 10^{-7}\ kWh$.

The task:

For how long will a light bulb light with a use of energy of 0.006 kW per hour for which energy will be obtained by burning 1 kg of PVC? The calorific value of PVC is 22.5 MJ / kg.

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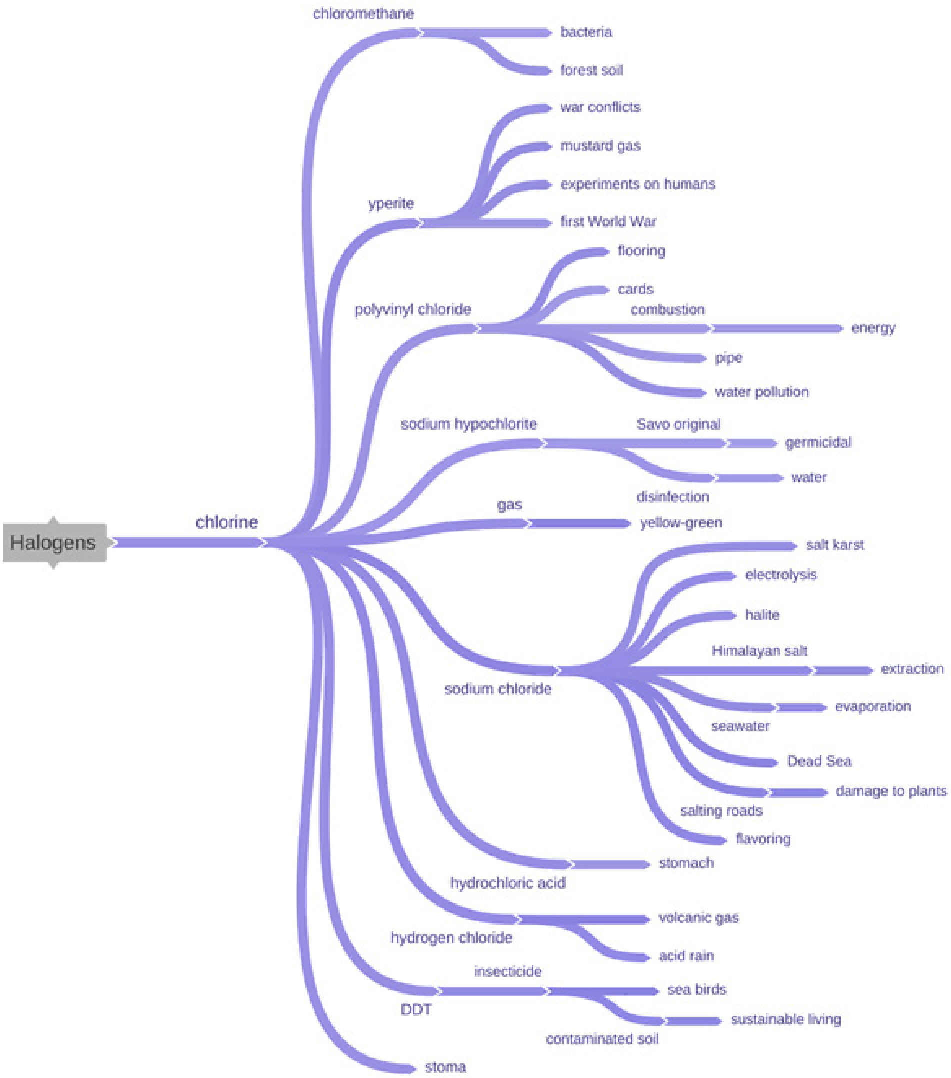
Figure 1a

Mind Map "Halogens" (Mind map was made using Coggle https://coggle.it/)

Figure 1b
Mind Map "Halogens" (Mind map was made using Coggle https://coggle.it/)



Conclusions and Implications

Based on previous research one of the main reasons for not implementing integrated teaching into lessons is a lack of suitable teaching materials. In this contribution new method that can be used for making integrated worksheets for all subjects of educational area Man and Nature is described with a practical example. A united method for making worksheets for integrated (science) teaching is important so a database of worksheets for integrated (science) teaching can be made and one of the main obstacles for not implementing integrated teaching into lessons (lack of suitable materials) can be overcome.

Acknowledgements

This article was elaborated within the activities in support of study programs specifically focused on the preparation of teachers with deficit teaching specialization at non-pedagogical faculties of public universities financed from the institutional support of the Ministry of Education, Youth and Sports for 2021.

Declaration of Interest

Authors declare no competing interest.

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Received: *May 22, 2021* Accepted: *July 24, 2021*

Cite as: Bartoňová, M., & Kričfaluši, D. (2021). The methodology for creating worksheets for integrated science. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 7-15). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.07

A NEW PERSPECTIVE ON MATHEMATICS EDUCATION COMING FROM HISTORY: THE EXAMPLE OF INTEGRAL CALCULUS

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Abstract

This research deals with a possible use of history of mathematics in mathematics education. In particular, history can be a fundamental element for the introduction of the concept of integral through a problem-centred and intuitive approach. Therefore, what follows is dedicated to the teaching of mathematics in the last years of secondary schools, where infinitesimal calculus is addressed. The thesis here proposed is that the resort to Archimedes' use of exhaustion method and to Newton's initial lemmas expounded in his Principia Mathematica *are useful means to reach a genetic comprehension of the concept of integral. Hence, two demonstrations by Archimedes and two lemmas by Newton are used to prove such thesis. A further idea here proposed is that history of mathematics can be of help for an interdisciplinary education.*
Keywords: *interdisciplinary education, mathematics education, science history, secondary schools*

Introduction

This research concerns the possible use of the history of mathematics within mathematical education in the last two years of the secondary schools because it regards the teaching of integral calculus.

History of mathematics can be a useful element in mathematics education because:

1) starting from history, the pupils can understand the conceptual origin of the mathematical concepts and to realize that they have been created to solve «concrete» mathematical problems. The formalization of the concepts is a successive step, when the numbers and the width of problems increased, and the necessity of precise definitions became necessary. However, if the teaching begins with the formal apparatus there is the risk that the learners do not guess its scope and utility and mistake the real meaning of the formalization.

2) A historical approach is useful for the students to realize the human aspect of mathematics. Mathematics exists thank to the hard work of the mathematicians. It is a human activity in which before reaching the final presentation of a concept or solution of a problem, a long history of failures, attempts and improvements has been needed. Mathematics, if appropriately presented is neither sterile nor mechanic, though, obviously, several technicalities have to be learned.

3) Nowadays «interdisciplinarity» is a common place, but to conceive an, at

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least partially, interdisciplinary education is not easy. History of mathematics can be of help. We will speak of Archimedes and Newton in reference to the birth of integral calculus. It might be possible to conceive an educational itinerary in which the teachers of history, physics, mathematics, and history of philosophy (where this discipline is taught) collaborate. For example, in the programme of history, it would be possible to stress the aspects connected to history of science and in the programme of physics the genetic problems which determined the introduction of certain concepts might be highlighted. In this way, an education based both on the connection of different subjects and on the understanding of the conceptual grounds of each specific discipline could be implemented.

Area of Curvilinear Figures and Integral Calculus

The example I am proposing concerns the calculation of curvilinear and mystilinear areas. Today the integral calculus and the concept of definite integral is used. The integral calculus is taught in the secondary schools after the formal introduction of the concepts of function, of limit and of the differential calculus. I am not claiming this educative methodology to be incorrect. Rather, a different one will be proposed for the teachers to have diverse options to follow in the difficult enterprise to make mathematics an interesting subject for most learners. The teachers themselves will be able to decide, according to pupils' level and propensities, the most appropriate approach.

Thus, before introducing the formal concepts of infinitesimal calculus, it would be possible to proceed like this: introduce only the concept of function. After that, analyse the way in which the problem of the calculation of curvilinear areas was faced by Archimedes (287-212 B.C.). This will offer the possibility:

a) to understand what the concept of limit is and to grasp that it is necessary while dealing with the areas of curvilinear figure.
b) To guess the profound meaning of the proves *ad absurdum* as well as the nuances and the subtleties behind such difficult problems as those proposed.
c) to comprehend the greatness and limits of Archimedes' approach as well as the necessity to overcome such an approach if you intend to achieve a general treatment of curvilinear areas. Therefore, Newton's concept of integral will be introduced.
d) Finally, after that the learners will have understood all the conceptual and computational bases of the infinitesimal calculus, a more formal approach will be proposed. But now the learners will fully grasp the conceptual meaning of such a formalization.

Archimedes and the Exhaustion Method: First Example

The procedures of Archimedes are extremely interesting because they seem an «anticipation» of the integral calculus, at least from a conceptual, if not operative, standpoint.

In fact, Archimedes invented two methods correlated to the calculations of curvilinear surfaces and volumes: the method of barycentres and the method of

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exhaustion. We will focus on two examples of the latter. The method of exhaustion was invented by Eudoxus of Cnidus (first half of the 4th century BC) and it is also used in the last books of *Euclid*'s Elements (Euclid 2008, Book XII, Propositions 2, 5, 10, 11, 12, 18, pp. 473-475, 480-481, 486-495, 503-504). However, Archimedes was the true master of this method.

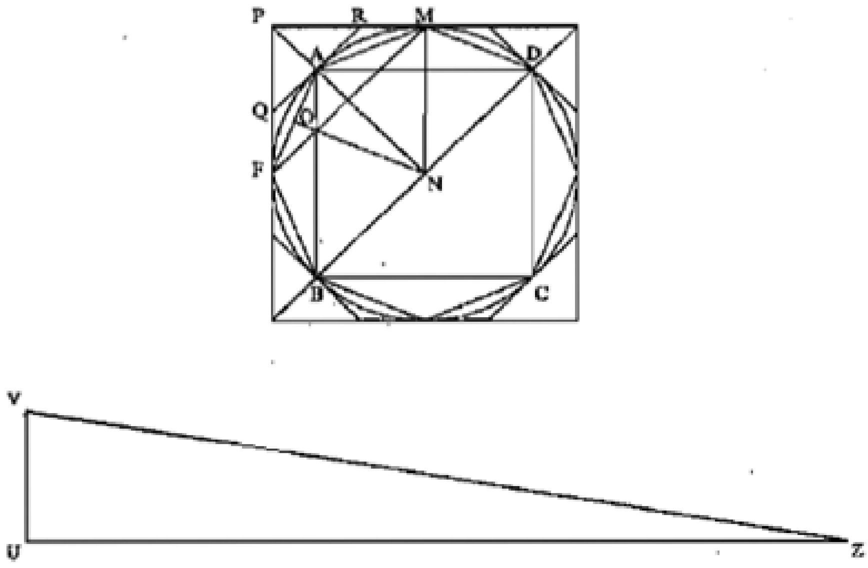
It works like this: you want to prove that two quantities A and B (areas or volume of two figures) are equal. Suppose they are not and be $A>B$. You construct a series of figures which approximate the figure A by defect and among them you find one whose difference from A is less than the supposed difference A-B. Then, you are able to prove that this figure should be, at the same time, greater and less than B, which is absurd.

Afterwards, you suppose $A<B$ and, in a similar manner, you show a figure which should be bigger and less than B. Absurd. Since A cannot be either greater of less than B, it is equal.

The area of the circle. From the first years of the secondary schools, the pupils know that, given a circle whose radius is r, its surface is πr^2. However, if you ask them to prove this statement, though in an intuitive manner, probably no one will answer the question, because the answer is not easy (try to do this «experiment»).

The first mathematician to solve such a problem was Archimedes in his work *Measurement of the circle* (Archimedes 2010, pp. 91-98). He developed the following brilliant reasoning to prove that «Each circle has the same surface as the right triangle E of which a leg (cathetus) is equal to the radius and the other leg to the circumference».

Figure 1
The Diagram Drawn by Archimedes to Determine the Circle's Area



Note: Adapted from Archimede 1974, p. 226. The editor uses Latin rather than Greek letters to indicate points

Archimedes proceeds like this (Fig. 1): suppose the circle *ABCD* to have an area *S* greater than *E*. It is possible to inscribe the square *ABCD* of area *Q* in the circle. Suppose $Q<E$ or, as Archimedes would say, the area of the four circular segments *AD, DC, CB, BA* is bigger than the difference by which the area of the circle exceeds the area of the triangle *E*. Bisect the four arcs of circumference *AD, DC, CB, BA*. Be *F* and *M* two of such points of bisection. Let us construct the regular octagon *FA, AM, MD, …*, whose area is *O.* Suppose $O>E$, or, as Archimedes wrote, that the sum of the areas of the eight circular segments *FA*, *AM*, *MD*, … is less than the difference by which the area of the circle exceeds the area of the triangle *E* (if you suppose $O<E$, it is possible to continue bisecting the arcs of the circumference until reaching a polygon of 2^n sides whose area is greater than *E*, but less than *S*). From the centre *N* of the circle, draw the perpendicular *NO* to the side *AF* of the octagon. Such a segment is less than the altitude of the triangle, which is equal to the radius. The octagon's perimeter is less of the rectified circumference.

Therefore, the octagon's area is less than *E*. But this is absurd because we have supposed $O>E$. Therefore, the area of the circle cannot be greater than that of the triangle.

Through a similar reasoning it is possible to prove that the area of the circle cannot be less than that of the triangle.

Commentary to use in an educational perspective. The just expounded demonstration gives rise to several comments which are very instructive. Some of them concern the internal logic of the proof; others are relative to the concepts used by Archimedes in comparison to modern notions. Let us begin with the first kind of comments:

a) In the proof there is a critical point: Archimedes seems to give for granted that the perimeter of the polygon inscribed in the circumference is less than the circumference itself. In fact, this problem does not exist because in the assumptions of his work *On the sphere and cylinder* Archimedes writes as first Assumption: "Of all lines which have the same extremities the straight line is the least" (Archimedes 2010, p. 3).

b) Further possible problem: it might happen that the difference between the area of the circle and that of the inscribed polygons diminishes but without tending to 0. Archimedes considered this problem, too. In propositions 3-6 of the first book of *On the sphere and cylinder,* he proved to be possible to inscribe in or circumscribe to a circle a series of regular polygons whose area has any ratio (or difference) with the area of the circle (Archimedes 2010, pp. 6-10).

Now let us come to commentaries which are useful not only to compare the modern concepts with those used by Archimedes, but also to introduce the learners to such concepts showing that their necessity derives from "concrete" mathematical problems as the one we are analysing. I am specifically referring to the notion of limit: it is usually introduced as the limit of a function. Given a function f:R→R and a point x_0 of its domain you say that $f(x) = l$, if for any real number $\varepsilon > 0$, a real number δ exists such that, if $|x - x_0| < \delta$, then $|f(x) - f(x_0)| < \varepsilon$. This definition is easily adaptable to the cases in which x tends to infinity or l is infinite.

Now, what is present in Archimedes' proof is the limit of a series of figure of which we consider the function-area, which can be reduced to a real function. To be more precise, Archimedes - to transcribe his idea in modern terms - considers as domain the perimeters of the regular polygons whose number of sides is of the form 2^n, also including the circumference – let us name *P* such a set – and, after that, the areas of

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each of such figures, also including the area of the circle – let us name *S* such a set – regarded as functions of the perimeters. The perimeter and the areas are real numbers; therefore, the function-area *f* can be represented as : $R \rightarrow R$. Be P_0 the length of the circumference and *P* the perimeter of any inscribed polygon, so that $f(P_0)$ is the area of the circle and $f(P)$ is the area of the regular polygon whose perimeter is *P*. Thus, in the reasoning of Archimedes it is implied that, for any real number $\varepsilon > 0$, a real number δ exists such that, if $|P - P_0| < \delta$, then $|f(P) - f(P_0)| < \varepsilon$. This is a simple transcription in a modern and relatively formalised language of what exists in Archimedes. There is no interpretative stretch. Hence, from an educative point of view, it is to highlight that this easy proof offered by Archimedes seems a natural way to introduce the concept of limit of a function; before in an intuitive manner – as the teacher might simply say that, when the difference between the perimeters of the inscribed polygons and the circumference becomes smaller and smaller, the same happens with the differences between the area of the polygons and that of the circle – and, afterwards, in a more formalised way.

On the other hand, it is appropriate to show the pupils a characteristic of Archimedes proof: the concept of limit is not used to develop a calculation through which to compute by means of formal steps, which might be repeatable, *mutatis mutandis*, to solve other problems. Rather, it is used to develop an *ad absurdum* reasoning which works because of the specific characteristics of the regular polygons inscribed in a circle. Therefore, while, in the genial Archimedes' procedure the general concept of limit is present, a general method to calculate the areas of, at least, a class of curvilinear figures is missing. As we will see, there are "ingredients" and ideas which can be used in other cases, but a general method of areas calculus lacks. Therefore, the students will perfectly understand the need to develop a method more general than Archimedes'.

An interesting and very instructive consideration concerns the way in which Archimedes used the ad *absurdum reasoning*. In this kind of proves, the assumption the theorem to be false (in particular, the assumption that the area of the triangle *E* is less than that of the circle) implies a proposition *p* and its negation not-*p* to be true. In our case the proposition *p* is: «the area of the octagon is bigger that the area of the triangle». The proposition not-*p* is not a proposition which is true because it is an axiom or a theorem previously demonstrated, as it happens usually in the *ad absurdum* proves. Rather, the propositions *p* and not-*p* are both deduced during the argumentation. In a sense, in this proof, and in general, in the proves for exhaustion, the hypothesis the theorem to be false destroys itself. There is not a contradiction with an already established truth. This is a particular of the exhaustion method worth being stressed to the pupils.

Archimedes and the Exhaustion Method: Second Example

It is appropriate to present a further example of the way in which the exhaustion method can be applied because the conceptual and didactical considerations which can be drawn hold a remarkable educative value.

The theorem whose prove will be proposed concerns one of the most famous results obtained by Archimedes: the surface of every sphere is the quadruple of its great circle. Namely, if *r* is the radius of the sphere, its surface is $4\pi r^2$. This statement is proved by Archimedes in *On the Sphere and Cylinder* as Proposition 33 of the first book (Archimedes 2010, pp. 39-41). Five other theorems proved by Archimedes in the same

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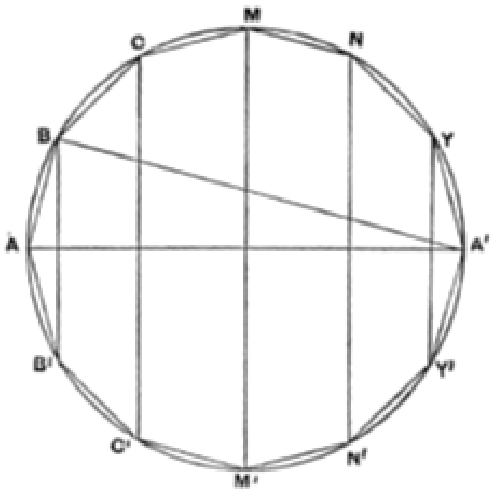
work are necessary along the demonstration. For convenience of the reader, I mention them:

1) Theorem I: Given two unequal magnitudes *A* and *B*, with *A*>*B*, it is possible to find two segments, whose lengths are resp. *S* and *s* such that *S*: *s* < *A*: *B*. (*On the Sphere and Cylinder*, I, 2, Archimedes 2010, p. 5).
2) Theorem II: Given two unequal magnitudes *A* and *B*, with *A*>*B* and a circle, it is possible to inscribe a regular polygon of side *l* and to circumscribe a regular polygon of side *L*, so that *L*: *l* < *A*: *B*. (*Ibidem*, I,3, pp. 6-7).
3) Theorem III: Consider a regular polygon *ABCM*... whose number of sides is of the form 4*n*, being *n* a natural number, inscribed in a great circle of a sphere. Rotate this polygon around the sphere's diameter *AA'*, then the area of the figure obtained by a complete rotation is less than four times the area of the sphere's great circle (*Ibidem*, I, 25, pp. 32-33).

Figure 2

The Diagram Used by Archimedes to Prove Proposition 25, book I, On the Sphere and Cylinder



Note: Retrieved from Archimedes 2010, p. 32. The editor uses Latin rather than Greek letters to indicate points.

4) Theorem IV: If the regular polygon of 4*n* sides is circumscribed to a great circle of the sphere, and it rotates around a sphere's diameter in a manner similar as the polygon of the previous theorem, the area of the figure obtained by a complete rotation is bigger than the area of the sphere (*Ibidem*, I, 28, p. 35-36).
5) Theorem V: Consider the figure of rotation constructed in the two previous theorems: the areas of the circumscribed and of the inscribed figures are as the squares of the sides' ratio of the polygon circumscribed to the great circle of the sphere to that inscribed. The volumes of the two figures are as the cubes of the sides (*Ibidem*, I, 32, pp. 38-39)

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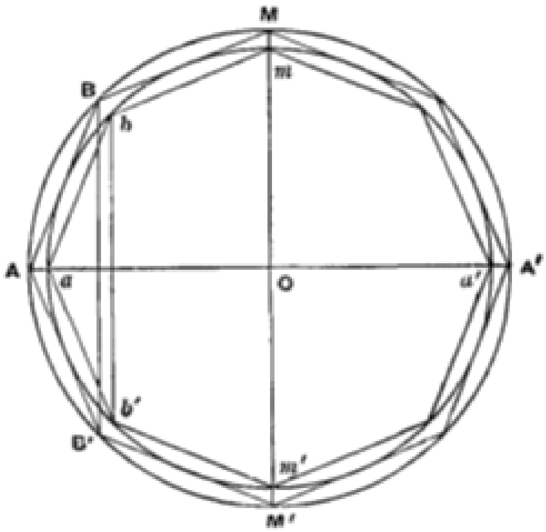
Figure 3
The Diagram Used by Archimedes to Prove Proposition 32, Book I, On the Sphere and Cylinder



Note: Retrieved from Archimedes 2010, p. 38. The editor uses Latin rather than Greek letters to indicate points.

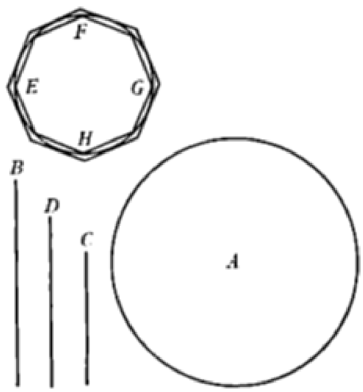
Let us not see Archimedes' proof of Proposition 33: be S a sphere and A a circle equivalent to four time the sphere's great circle. It is required to prove that the surfaces $s(S)$ of S and $s(A)$ of A are equal. Suppose, *ad absurdum*, $s(S) > s(A)$. Under this hypothesis, it is possible to choose two segments B and C such that $\frac{B}{C} < \frac{s(S)}{s(A)}$ (Theorem I). Be D the mean proportional between B and C, namely $B: C = D: C$. Be the sphere cut by a plane through its centre along a great circle $EFGH$. Inscribe in and circumscribe to the sphere two similar polygons with a number $4n$ of sides, under the condition that between the side P of that circumscribed and the side p of that inscribed the relation $P: p < B: D$ (Theorem II) holds. Consider the figures generated as in Theorem III and IV. Indicate the surface of that inscribed as $s(I)$ and the surface of that circumscribed as $s(C)$. Then $s(C): s(I) < s(S): s(A)$, which can be deduced by the following series of steps:

I.	$s(C): s(I) = P^2: p^2$	(Theorem V).
II.	$P: p < B: D$	(Assumption).
III.	$B:C < s(S): s(A)$	(Assumption).
IV.	$B: D = D: C$	(Assumption).
V.	$B: C = B^2: D^2$	(Direct consequence of IV).
VI.	$s(S): s(A) > B^2: D^2$	(From III and V).
VII.	$B^2: D^2 > P^2: p^2$	(From II).
VIII.	$s(C): s(I) < s(S):s(A)$	(From I, VI and VII).

However, this is impossible because $s(C) > s(S)$ (Theorem IV) and $s(I) < s(A)$. This absurd conclusion implies that the area of the sphere cannot be bigger than four times the area of its great circle. Through an analogous reasoning, Archimedes proved that it cannot be even smaller. Thence, it is equal.

Figure 4

The Diagram Used by Archimedes to Prove Proposition 33, Book I, On the Sphere and Cylinder



Note: Retrieved from Archimede 2004, p. 154. The editor uses Latin rather than Greek letters to indicate points

Commentary to use in an educational perspective. This proof offers many reasons of interest which can represent useful ideas to develop from an educative standpoint. They concern the internal logic of the proof and its level of generality. Let us begin with the first question.

Logic of the proof: in the demonstration concerning the area of the circle, Archimedes used the difference between the area of the circle itself and the area of the inscribed (circumscribed) regular polygons of 2^n sides. The area of those inscribed (the case we have analysed) approximate with an arbitrary exactness the area of the circle.

In this second proof, the idea is to resort to ratios rather than to differences. One might say that the space between the areas of the circumscribed and the inscribed figures include the area of the sphere the more precisely the more the number of the sides of the polygons inscribed and circumscribed to a great circle of the sphere increases. In particular, to prove *ab absurdum* that the ratio $\frac{s(S)}{s(A)}$ cannot be greater than 1, Archimedes used the fact that the ratio $\frac{s(C)}{s(I)} > 1$ and that $\frac{s(C)}{s(I)} > \frac{s(S)}{s(A)}$. Thus, his *ad absurdum* construction can be represented like this:

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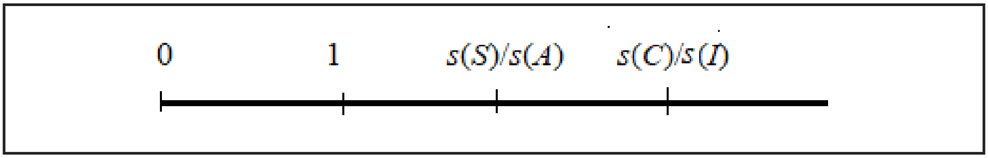
Figure 5
Diagram which Summarizes Archimedes' Reasoning. Adapted from Archimede 1974, p. 152



During the prove he demonstrated that, supposing $\frac{s(S)}{s(A)} > 1$, you reach a situation where $\frac{s(C)}{s(I)} < \frac{s(S)}{s(A)}$, which is impossible.

Where is the concept of limit here involved? It is involved in the construction which exploits theorem III because, if you indicate by 1 + ε the ratio *A/B*, being an arbitrary real number (but, of course, we are interested in the case in which ε is "very small), this theorem states that *L*:*l*<1 + ε, namely that it tends to 1, which, in its turn, implies that the ratio between the areas $\frac{s(C)}{s(I)}$ can differ from 1 by any arbitrary small value. This allows Archimedes to insert, *ad absurdum*, $\frac{s(C)}{s(I)}$ between 1 and $\frac{s(S)}{s(A)}$. Thus, the concept of limit is implied in this demonstration and is in every proof by exhaustion.

We have seen two different applications of the exhaustion method, one based on the difference and one based on the ratio between figures. The latter application is more complex than the former because in the former only two figures are used in the proof (the circle and the series of the inscribed polygons, in the part of the proof here proposed; the circle and the series of the circumscribed polygons in the other part), whereas in the latter three figures are used at the same time: the series of circumscribed figures, the sphere, and the series of inscribed figures.

The first form of the exhaustion method can be called *by approximation*, the second form *by compression based on a ratio*. There is a third form, namely the *compression based on a difference*, but it is not necessary to enter further details for the aims of this research (on this subject see the seminal, pp. 130-133).

These logical considerations here presented are rather subtle and can be extremely useful to develop the logical capabilities of the learners. Thus, it is advisable that the teachers develop them in front of the learners. This will be instructive. Let us move on some more general reflections.

General reflections on Archimedes' method. Archimedes proved several theorems by exhaustion. The two demonstrations we have seen are paradigmatic of some general features which connote all the proves by exhaustion:

a) The concept of limit is present and well conceived. Archimedes guessed that the only way to calculate, in general, the areas and the volumes of curvilinear or mystilinear figures was to approximate them with an infinite series of rectilinear figures, or, at least, of figures whose areas or volumes were already known.
b) What expounded in the item a) is sufficient to define that of Archimedes a method, in the sense that each prove by exhaustion is based on some leading ideas which are always the same. On the other hand, the exhaustion method is

not a systematic procedure which can be applied always in the same manner to calculate areas and volumes. For every figure Archimedes analysed, some specific theorems and constructions are necessary. They are not logically deducible from the theorems and constructions applied in different cases. Thus, the exhaustion method is not a mechanical procedure based on constant and invariable steps. Though a series of general ideas exist, each case requires some different specific reasonings.

c) Furthermore, Archimedes, as it is typical of the tradition of Greek mathematics, does not offer the numerical value of the required area or volume, but proves the identity of an unknown area with a known area. It is, however, to point out that in no works of the Greeks mathematics you find explicit formulas such as "area of a triangle is equal to basis by altitude". In Euclid's *Elements* there are propositions (See, for instance Euclid 2008, I, 36, pp. 37-38 for the area of a parallelogram and Euclid 2008, I, 37-I, 40 pp. 38-41 for the area of a triangle) from which it results clearly that the Greeks had reached many elementary formulas for areas and volume, but such formulas are not explicitly stated.

d) The exhaustion method is not a heuristic method; it is a demonstrative method, which does not allow you to calculate the value of a certain area or volume if you do not know it; rather, it permits to prove an area or volume to be equal to another area or volume if you have reached this result otherwise. This is understandable if you think that we are speaking of an *ab absurdum* procedure.

e) Finally, a brief historiographic note has to be added: many important historians of science thought that Archimedes' method of exhaustion contains most of the elements typical of the integral calculus. Heath, albeit with many reservations and specifications on the use of the infinite in Greek mathematics, basically thought that Archimedes' exhaustion method "anticipated" integral calculus (Heath in Archimedes 2010, pp. CXLII-CLIV). Many other scholars followed his opinion. In contrast to this view, far more recently, Napolitani and Saito have underlined the fundamental differences between Archimedes' procedure and infinitesimal calculus. According to their train of thoughts, there is no generality in Archimedes' exhaustion proves (see, i.e., Napolitani 2001, Saito 2013). My opinion, as also clarified in these pages, is in between the two: the concept of limit is present in Archimedes in almost modern form, but nothing as a calculation of limits, a necessary – though not yet sufficient - ingredient for the integral calculus, exists (see also Bussotti 2019). I point out that, in this item, I have given only a very slight idea (the aim of this research is not historical, but educative) of a complex and articulated historiographical debate, with a great number of protagonists.

Once described this fascinating picture, which can arouse the interest and the curiosity of the pupils, the reason to look for a general method which will permit to calculate directly the numerical value of curvilinear areas and volumes will be evident. The teachers, at this point, might ask the pupils which elements of the Archimedes' method they think to be necessary in order to develop a general procedure and which elements have, instead, to be modified. The result of this discussion should be that the notion of limit has to be conserved as well as the idea to approximate the curvilinear areas and volumes with known areas and volumes. It is clear that the next step will be to better clarify the techniques of approximation. The aim is to transform Archimedes' use of approximation, which is genial and correct, but which needs a new different idea for any application, into a systematic procedure. This process will bring to the concept of integral. In this manner, the learners will understand profoundly the problem behind mathematics, which will, hence, result to be a conceptually rich discipline and not merely a set of techniques to learn by heart. The best way to introduce this further step is Newton's work.

Newton and the Concept of Integral

Newton dedicated several of his works to the concept of integral and to the integral calculus. However, for our aims, it is sufficient to analyse the lemmas on the concept of integral included by Newton in the first section of his *Mathematical Principles of Natural Philosophy* (1687 first edition, 1713, second edition, 1726 third edition; see Newton 1999), which is entitled "method of first and last ratios". Here the concept of limit is used in an almost modern manner and more explicitly than in Archimedes, though its formalization in ε-δ terms was given only in the 1820s. Newton's text opens with the celebrate "Lemma I", which states:

> "Quantities, and also ratios of quantities, which in any finite time constantly tend to equality, and which before the end of that time approach so close to one another that their difference is less than any given quantity *d*, become ultimately equal".
> Proof: "If you deny this, let them become ultimately unequal, and let their ultimate difference be *D*. Then they cannot approach so close to equality that their difference is less than the given difference *d*, contrary to the hypothesis". (Newton 1999, p. 433).

Two considerations can be proposed in an educative context:

1) Newton considers two quantities or two ratios of quantities whose difference tends to become smaller than any given *d* and claims their limit to be 0. This is the meaning of the expression that the two quantities or ratio of quantities "become ultimately equal". What Newton indicates with *d* has the same meaning as ε in the formal definition of limit. However, Newton proceeds in a manner which is slightly different from ours: he considers the limit of two quantities which are both functions of the time. In practice, Newton is claiming that if, being $g(t)$ and $f(t)$ functions of the time t and if $\lim_{t \to t_0} g(t) - f(t) = 0$ (or equivalently if $|t - t_0| < \delta$, then $|g(t) - f(t)| < \varepsilon$ or d, as Newton writes) the values of the two functions can be considered equal in t_0, which is absolutely true if g and f are continuous in t_0, as Newton implicitly presupposes. In an educative perspective, it is important to remark that the reference to the concept of function is a way to grasp Newton's ideas and to transcribe them in a language the pupils know and which creates, hence, no problem. However, properly speaking, Newton did not have the concept of function. For, he spoke of "quantities" which is a very generic expression that cannot be identified with our formal notion of function. This notwithstanding,

the concept of limit can subsist and correctly used also in a mathematics in which the notion of function is not exactly stated, though we refer always the limit to the functions. Only as a consequence to solve mathematical problems for which the concepts had to be defined in a more perspicuous manner, we reached the formal definition of basic notions such as function and limit of a function.

2) Newton sees the concept of limit in a dynamical, a physical manner. For, the independent value is time and, hence, the functions $g(t)$ and $f(t)$ represent, at least in principle, physical quantities. It is intuitive that they might represent spaces expressed in function of time, or velocities, or accelerations varying in the time. It will be instructive to show that, at the dawn of modern science, the concept of limit was presented not in terms of a generic and abstract independent variable, but in terms of the variable Newton assumed as the ground of his physics: time. In spite of the fact that time is a specific variable, Newton's procedure has a general value, whatever the independent variable be.

Let us now see how Newton introduced the concept of integral.

Lemma II: «If in any figure *AacE*, comprehended by the straight lines *Aa* and *AE* and the curve *acE*, any number of parallelograms *Ab, EC, Cd*, ... are inscribed upon equal bases *AB, BC, CD*, ... and have sides *Bb, Cc, Dd*, . . . parallel to the side *Aa* of the figure; and if the parallelograms *aKbl, bLwcm, cMdn*, ... are completed; if then the width of these parallelograms is diminished and their number increased indefinitely, I say that the ultimate ratios which the inscribed figure *AKbLcMdqD*, the circumscribed figure *AalbmcndoE*, and the curvilinear figure *AabcdE* have to one another are ratios of equality».

Proof: «For the difference of the inscribed and circumscribed figures is the sum of the parallelograms *Kl, Lm, Mn*, and *Do*, that is (because they all have equal bases), the rectangle having as base *Kb* (the base of one of them) and as altitude *Aa* (the sum of the altitudes), that is, the rectangle *ABla.* But this rectangle, because its width *AB* is diminished indefinitely, becomes less than any given rectangle. Therefore (by Lemma 1) the inscribed figure and the circumscribed figure and, all the more, the intermediate curvilinear figure become ultimately equal».

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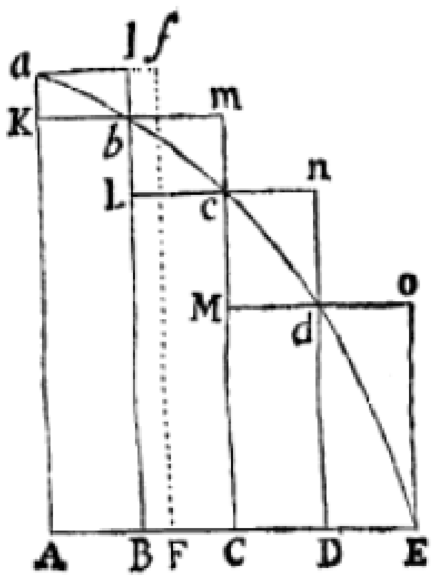
Figure 6
The Diagram Used by Newton to Prove Lemma II.



Note: Retrieved from Newton, 1726, p. 28

In this Lemma the concept of integral is clearly stated. For, the teacher, relying upon clear and intuitive Newton's explanations might give a first visual idea of what the integral of a function is as follows: you have to calculate the area of the curvilinear region included between the graphic of the drawn function and the *x*-axis (Fig. 7) in the interval (*a,b*). Such interval is divided into a certain number of partitions. A series of rectangles is drawn whose sum approximates by defect the searched area and a series of rectangles whose sum approximate by excess. Under appropriate conditions, when the interval $x(i)$-$x(i+1)$ tends to 0 and the number of the infinitesimal rectangles tend to infinity, the sum of the series of the rectangles which approximate by defect and the series of that approximating by excess tend to the same value. Such a value is assumed as the required area.

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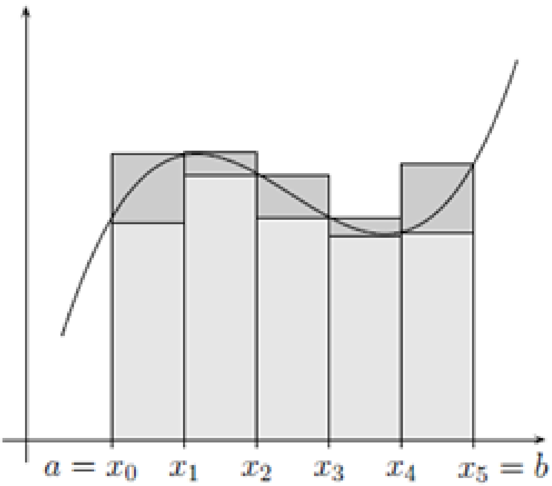
Figure 7
A Figure which can be Used to Give an Intuitive Idea of the Concept of Integral



All these steps are already present in Newton, thought in a less formalised manner than ours because the concept of function was not yet defined and that of limit was, consequently, conceived in a manner slightly different from ours. But all the fundamental ingredients of the integral calculus exist in Newton. Starting from the work of this great scientist it is, hence, possible to propose an intuitive, but, however, rather precise approach to the notion of integral. Here, you have a positive idea which can be developed into a technique or a series of techniques to calculate curvilinear areas and volumes. By the way, Newton himself developed many of such techniques. The stage in which the infinitesimal concepts are used as demonstrative means to which no technique of calculus was associated has been overcome, thanks to Newtons' idea to consider the area of a curvilinear figure like in the Lemma II.

Newton introduced two other lemmas on the integral calculus, the Lemma III, and Lemma IV. The former is particularly worth being mentioned: Newton shows that the same conclusions drawn in Lemma II hold if not all the bases of the parallelograms are equal, granted that all decrease at infinity. Some corollaries follow, the most interesting of which is the fourth one, which, from our standpoint is remarkable because Newton claims that the figure obtained increasing more and more the number of the majorant and the minorant parallelograms and whose perimeter is *AcE* (Fig. 6) is not anymore a rectilinear figure, but the curvilinear limit of a series of rectilinear figures. In this context he used explicitly the Latin term *limites* (plural), that is limits, which means that, also from a terminological point of view, his conceptions are similar to ours, or better ours are similar to his!

At this point, once understood the fundamental characteristics of the concept of integral thanks to Newton's work, the pupils will also realize that a formal definition of function, limit and integral will be necessary to fully guess to what extend the concept and the techniques of integration developed by Newton can be extended. Now the entire preparatory work to introduce the notion of limit and of integral in a genetic, problem-centred and intuitive way is finished and the learners will be ready to accept more formal definitions, which will be easy to be understood after this conceptual introductory work.

Conclusions and Implications

The effort of this research has been to show in the concrete case of integral calculus the way in which history of mathematics could be used in an educative context. We have seen the advantages of a historical approach insofar as it allows the pupils to understand not only the chronological origin of the concepts, but also the genetic-conceptual one. Through this approach, they will comprehend the progressive constructive steps through which the edifice of mathematics has been built. The advantage of this educative standpoint relies also upon the possibility to develop an interdisciplinary approach with other subjects such as physics, history and history of philosophy. Furthermore, the teacher has a great freedom to choose the historical itinerary he prefers. For example, in reference to integral calculus other authors different from Archimedes and Newton might have been chosen. The didactical itinerary, if well conceived, would have been equally valid. It is important to show how the educative path here proposed might be continued so as to include the differential calculus: for, following Leibniz's train of thoughts, it will be possible to show that the operations of drawing the tangent to a curve and of identifying the points of maxima and minima are opposite to that of calculating an area. This is very interesting because it will allow the pupils to intuitively understand what today we call the fundamental theorem of integral calculus, that is (to simplify) the fact that derivation and integration are two opposite operations. Such result will be achieved through the analysis of concrete problems (calculations of areas, of tangents and of maxima and minima), which could represent a stimulus for the pupils to increase their interest towards mathematics.

For all the reasons expounded in this research, a historical approach to mathematics education is highly recommendable.

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Received: *May 28, 2021* Accepted: *July 28, 2021*

Cite as: Bussotti, P. (2021). A new perspective on mathematics education coming from history: The example of integral calculus. In V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 16-31). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.16

ASSUMPTION OF COGNITIVE GOALS IN SCIENCE LEARNING

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Abstract

A new didactical approach named "Learning by Being" (LBB) is proposed and its correlation with current educational paradigms in science teaching is analysed. The key idea in LBB is the assumption by the students of cognitive goals, and three components are mandatory in LBB: a) student's personal learning effort, b) student – teacher mutual feedback and c) metacognition. In other words, the ownership of cognitive goals and students' deep intrinsic motivation. Several didactic approaches, used within LBB, are analysed: independent research that has an impact factor on cognitive achievement equal to 83%; knowledge of success criteria (impact factor – 113%); ability to reveal similarities and patterns (impact factor – 132%). The core of LBB is guided learning effort that corresponds to the notion of teacher–student harmonic oscillator when both things – guidance from teacher and student's effort – are equally important.
Keywords: *conceptual understanding, learning by being, ownership of cognitive goals, science learning*.

Introduction

The problem of low students' motivation and interest for learning effort is one of most important in nowadays school. The majority of solutions for overcoming low motivation come from the constructivist area: learning by doing, active learning, learning by understanding, inquiry-based science education, problem– and project – based learning, etc. All these approaches differ in the degree of independence in learning. The higher is the degree the higher is impact of particular didactic strategy on academic achievement of school students (Hattie, 2017). In this way, increasing the students' independence degree in learning is the solution if we want to not only remove boredom but also achieve academic success of students.

This independence in learning should go until it will reach the student's ownership on learning goals. It means that the students both understand their way of learning and assume the didactic objectives as their own cognitive goals. It is about metacognition (Scharff et al., 2017). Thus, teachers' didactic goals should become students' learning objectives. This fact corresponds to the results of the theory of *visible teaching and learning* (Hattie, 2009). In order to obtain the assumption by the students of cognitive goals, the communication in the frame of the lesson should be based on mutual student – teacher feedback and the students' empowerment through metacognition (Millis, 2016).

In such a way, a modern didactic strategy contains three pillars: students' learning effort, enhanced student – teacher communication and metacognition (Calalb, 2020).

https://doi.org/10.33225/BalticSTE/2021.32

Considering these prerequisites, this short communication analyses several moments: the evolution of educational paradigms from *learning by doing* to *learning by being,* the correlation of students' learning effort with metacognition, the main features of multilateral student – teacher feedback (feedback from and to all students) and gives practical recommendations for applying learning by being concept in inquiry – based classroom.

From Learning by Doing to Learning by Being

The first step in the ladder of modern educational paradigms is *learning by doing* (LBD). For example, a form of LBD is *ludic education*. According to the results of the theory of *visible teaching and learning* (VTL), the impact factor on academic achievement of students for ludic education is 35% (Hattie, 2009). Compared with the benchmark level, which is equal to 40%, when an experienced teacher applies permanently the same conventional strategy during two academic years, LBD has a negative impact factor. These numbers demonstrate once again that school does not belong to entertainment industry and conventional teaching remains a solid option in modern times.

The second step in the mentioned ladder is *learning by understanding* (LBU). A well-known example of LBU is *inquiry-based science education* (IBSE) (Harlen, 2010), which has an impact factor equal to 77%. Thus, the effect of understanding is twice higher than the one of doing. The level or complexity degree of communication makes the difference between LBD and LBU. The communication should be seen as leverage for enhancing students' involvement degree in classroom activities.

The next step would be *learning by being* (LBB) when the students not only understand but also assume the learning objectives. In this way, within LBB, the students are the subjects of their learning process, construct their cognitive path, and form in class sustainable lifelong learning skills. It is about the students' *ownership on cognitive goals* (Calalb, 2019). Here we will present several characteristic features of LBB. For example:

- The ability of students to carry out *independent research*, in other words *guided self-scaffolding*, with an impact factor equal to 83%;
- *Knowledge of success criteria* or even more – assumption of success – the driving mechanism in learning, which is more than the knowledge by the students of evaluation criteria, impact factor on academic success is 113%. We have to emphasize that in order to achieve this level, students should be accustomed with IBSE. Years of permanent, daily IBSE implementation in classroom have to be seen as a mandatory prerequisite for this LBB approach.
- The ability of students for *revealing similarities and patterns*, which has an impact factor equal to 132%, is the ability to connect the new information with their previous knowledge "that is not forgotten". Thus, this approach relates to the formation of analytical and critical thinking skills, the basis for lifelong learning skills.

In this way in order to maximize the academic achievement of students, we should increase the independence degree of their learning. In other words, teaching should be seen as couching in sport when the athlete not only knows what the couch wants from him/her, but also assumes these tasks as own goal and has all physical, technical, tactical, and emotional means for achieving the goal set initially by the couch.

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Learning Effort and Metacognition

The main goal of contemporary education is the scientific understanding of the world by the majority of population. Despite many and various efforts for identifying adequate strategies for this goal, it remains Fata Morgana in education. The cause is minimisation of the importance of the learning effort or the search for royal ways in science. Learning through intellectual effort is a well-known didactical principle that reflects the fact that the ascension is only uphill. It suits to Vygotsky's concept of the *zone of proximal development*. Namely because of this ludic education has a negative impact factor. Intrinsic intellectual effort is the base for conceptual, scientific understanding of phenomena and things. There can be no understanding without student's intellectual effort in the atmosphere of empathy in classroom that encourages verbalisation and fosters communication. We should speak about education centred on student's learning effort rather than student centred education. Constructivist approach without learning effort is non-sense. Research suggests that constructivist teaching approach is not necessarily reflected in higher test scores but students familiar with constructivist classrooms scored much higher when they were asked to explain scientific phenomena, than students in traditional classrooms (Berube, 2001). Other results of pilot studies suggest that teaching programs based on 5E constructivist approach (engage, explore, explain, elaborate, and evaluate) increase motivation and remove boredom by creating positive impression to the learners (Arioder et al., 2020). Indeed, motivation and students' interest have to be seen as the first bricks in the foundation of any LBB approach when students' ownership of cognitive goals is targeted.

Learning by being concept is about not only students' assumption of learning process but also requires that students themselves are aware and understand their way of thinking in the case of learning, which is more than the application (or replication) of a learning activity taken from the teacher. It is about metacognition when students: a) are able for and analyse what type of strategy they will use to accomplish a particular task; b) estimate their possible result; c) analyse their result and decide if it is necessary to change the strategy to accomplish the task (Kirschner, 2006). Thus, the metacognition closely relates with the didactical principle of consciousness of learning.

Student – Teacher Mutual Feedback

Two-way communication channel is the mandatory component of any constructivist didactic strategy. According to VTL theory, teaching and learning should not be with closed eyes – the teacher doesn't know how the students have received his/her message, and students don't know and don't understand what the didactic objectives of the lesson are (Hattie & Donoghue, 2016). VTL analyses and measures the influence of more than 250 factors on academic achievement of school students. From these factors, several factors that directly influence the feedback have been selected. For example:

- Teacher's a *priory assumption* about the student's potential and aptitudes – with an impact factor equal to 162%
- Teacher's *instant knowledge on students' response* to his/her didactic action – impact factor equals to 129% (in other words teacher knows immediately what students think about his/her action).

https://doi.org/10.33225/BalticSTE/2021.32

- Teacher's ability to *coordinate classroom debates* within and among groups – 82%.
- Peer instruction – 74%.
- Formative evaluation – 48%.
- Student centred teaching – 36%.
- Problem – based learning – 26%.

The last two strategies are below the benchmark level of 40% mentioned above because in the case of student-centred teaching we have the student as the passive object of teacher's action and because the majority of teachers don't apply permanently PBL in their classes. These results are confirmed by PISA results in the Republic of Moldova where in three – four classes there is only one student with high depth of knowledge, compared with South Korea where there are three -four such students in one classroom (PISA, 2017).

The technical solution for instant feedback is digital classroom response system. Having such a system, the teacher will not "advance" to the next topic until at least 70% of students will understand the new notion or law. In this way, the instant teacher's knowledge of the effect of his/her didactic action on the students' understanding is three times more valuable than the assumption that the student would have retained something (knowledge of the effect – 129%, assumption – 40% (Nicol & Boyle, 2003).

Learning by Being within Inquiry-Based Science Education

Further, we will present the main steps to be followed by the teacher in the classroom, in order to achieve the assumption of the cognitive objectives by the students. In other words, how to put into practice the LBB concept in the frame of an inquiry-based science education (IBSE) project carried out by students. Here we present separately the teacher's role within IBSE lesson (namely teacher – student interaction, and students' group activities. Related to teacher we will analyse three moments: a) formation of students' ideas (this fact determines to what extent the students will assume the cognitive goals); b) guidance of students' own research activity, developed in groups; c) facilitation of analysis and drawing of conclusions (within debates at group and class level). Related to students' action we will describe: a) students' mandatory steps within IBSE classroom; b) development of group work; c) recording and analysis of measurement and/or research results, etc.

Teacher – student interaction

1. Formation of students' ideas

In order to reveal students' initial ideas, the teacher asks open questions and gives positive feedback to let students realize the necessity for the revision or development of their initial ideas.

2. Supporting students' own research

The teacher helps students to formulate productive questions such as "What is the shortest path, convenient form, etc. ...?" - which will form the basis for further research and guides the students in the planning of their further research. The teacher facilitates the planning process, providing a possible structure of the research plan. In addition, the teacher helps the students to record the measured data and to organize them in tables.

3. Guidance of students within analysis process and formulation of conclusions
The teacher asks the students to formulate as concisely as possible their conclusions, not only to say what the result of the measurements is, but what its meaning is. The teacher asks the students to check if the conclusions formulated by them correspond to the results of the measurements or observations. The teacher encourages students to reflect on what they have done and what conclusion they have reached.
Student activities
4. Conducting research
Based on their ideas, students formulate and explain their hypotheses. Students participate in planning the experience by discussing the details. Students do not create the research plan, but at least they understand and accept it. Here, in fact, we are talking about assuming the objectives of learning – according to the concept of LBB. Students analyse, compare, and explain the data obtained in relation to their hypotheses.
5. Group work
Students collaborate and share tasks being in the same group. Avoid individual work. Students report the results of group work in front of the whole class. Students – rapporteurs answer the asked questions, others approve, reject, or debate the results of the given group.
6. Recording the results
Students record what they have measured and what they have identified. All collected data are organized in the form of a table, i.e., any register must contain a table, so that students are familiar with the organization of the data collected in a table. Students note in the register if their results correspond to their hypothesis. The conclusion reached by the group is written in the register. Students also make their own notes, informal, with ideas or data, which they consider appropriate. Although informal in their content, these notes should be mandatory in order to form lifelong learning skills through inquiry-based learning.

Conclusions

This short communication presents the evolution of educational constructivist paradigms from the concept of *learning by doing* to the one of *learning by being* in terms of their impact on academic achievement of school students. The author emphasizes that active learning is not yet understanding, and its impact factor could be lower than conventional teaching. Moreover, apparent understanding is not equivalent to the formation of lifelong learning skills, or to the formation of that knowledge "which is not forgotten".

In order to achieve its main goal, namely scientific understanding of the world by the majority of population, the modern education should be based on students' learning effort and make them assume the ownership on learning goals. More simply, for students the desire and effort for knowledge should come intrinsically – the core idea of learning by being concept. Students' intrinsic intellectual effort is the base for their conceptual, scientific understanding of the world of things and phenomena.

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Along with intellectual effort, learning by being is based on metacognition, which relates with the didactical principle of consciousness of learning. It means that students not only understand what they do but understand their own way of thinking. In these given conditions, the teacher turns into a coach who must provide the emotional environment for *guided self-scaffolding*.

The concept of learning by being changes the format of teacher – student communication. For a fruitful learning process, we should have a permanent student – teacher mutual feedback. It is according with the *theory of visible teaching and learning* when both the student and the teacher have the same cognitive/didactic goals. In this sense, the author emphasizes that feedback – based strategies have the biggest impact factors. However, the most valuable strategies are those focused on the management of multilateral feedback or teacher's ability to coordinate the group work within inquiry-based classroom activities.

In order to give practical solutions for application of the concept of learning by being, the author structures both teacher and students' activity in classroom on the example of inquiry – based science education project. Thus, in the development of fruitful teacher – student interaction the teacher will focus on the following aspects: the formation of students' ideas; supporting students' research; guidance within analysis and drawing conclusions. Related to students, the most important for teacher is to focus on making students assume the objectives of the research, to manage their group work, and get them familiar with discussions and debates.

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Received: *May 29, 2021* Accepted: *August 02, 2021*

Cite as: Calalb, M. (2021). Assumption of cognitive goals in science learning. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 32-38). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.32

INCREASED STUDENT PERFORMANCE ON PHYSICS CONCEPT INVENTORY TEST AFTER STUDENT-CENTRED APPROACH IN UNIVERSITIES OF LATVIA

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Abstract

Education research has repeatedly shown that active learning in physics is pedagogically more efficient than traditional lecture courses. Widespread application of the active learning is slowed down by the lack of data on the performance of the active learning in widely varying circumstances of different educational systems. We measured the level of understanding of basic physics concepts using Force Concept inventory for students who enrol at different universities in Latvia in calculus-based and non-calculus-based groups and compared the student performance to the pre-test results elsewhere in the world. We measured the growth of concept inventory test results and studied the dependence of the growth on the teaching approach used by university lecturers. About 450 undergraduate students from 12 groups of science and engineering courses taught by 8 lecturers were involved in the study at three universities in Latvia. The Force Concept Inventory multiple-choice test was translated to Latvian and used for pre-/post-tests. The pre-test results showed that the maximum of the distribution of correct answers for non-calculus groups is around 20%, which is the value obtained by the random guessing of test answers, whereas the pre-test results of calculus-based groups was about 50% of correct answers. The test score after taking post-test confirmed that the growth of students' tests results is closely related to the teaching approach chosen by lecturer, showing that in order to provide physics graduates with a good conceptual understanding of physics, student centred teaching approach was crucial. The use of concept inventories in undergraduate physics education to measure the progress of learning appears to be particularly important in the current situation with a small number of students in physics and a critically small number of future physics teachers, when efficiency of teaching is of crucial importance.

Keywords: *STEM education quality, conceptual understanding, student-centred approach*

Introduction

In Latvia students are enrolled at universities after completing secondary education and after participating in Centralized Examinations organized by the State. There is no mandatory final exam in physics and students can enrol in the science and engineering faculties in Latvia without a physics exam grade. It is possible to be accepted at university only by the result of a mathematics final exam. Some Upper-secondary school graduates, who see their future in physics or engineering, choose the State

https://doi.org/10.33225/BalticSTE/2021.39

Centralized Exam in Physics. Since at the undergraduate level of physics, students may enrol at universities without physics exam, the teaching staff at universities must reckon with unpredictably varying initial knowledge and understanding of physics for different students at the beginning of physics courses. Lecturer's claim that the understanding of physics after upper secondary is generally low, but it is only a subjective point of view, usually communicated without further justification or quantitative measurement. The teaching of physics courses also benefits from measurement allowing to quantitatively characterize the growth of student's understanding of physics and growth of skills to apply physics laws, depending on the learning approach used in a course.

In order to measure the understanding of student's basic concepts of physics at the beginning of undergraduate physics courses and to determine the growth of understanding, Force Concept Inventory (further FCI) was used at several universities of Latvia during this research in 2018–2021.

Research Questions:

- How high is the level of understanding of the basic physics concepts of students who enrol in calculus-based and non-calculus-based groups, as objectively assessed by concept inventory and how does this level compare against FCI pre-test results elsewhere in the world?
- How high is the growth in concept inventory test results for students depending on teaching approach used by university lecturers?

FCI was developed and first applied by Hestenes, Wells and Swackhamer (1992, March). The evidence of their study was essential: "the knowledge gained under conventional instruction is essentially independent of the teacher" (Savinainen, 2002). A revised version of the FCI was developed and placed on the web in 1995 (Halloun et al., 1995) and later appeared in Mazur's book (Mazur, 1997). A detailed analysis of FCI results with large statistics, including six thousand students in the study, was performed by Hake (1998).

The growth of student understanding of basic physics concepts is measured as FCI gain. Gain described in studies ranges from about 20%, which is just a fifth of the student's potential achievement, up to about 70%. For example, Georgia States Universities, US, recent study using FCI test included more than 5,000 students showed the average gain that range from 47.4% up to 71.3% (Caballero, Greco, Murray, Bujak & Marr, 2012). Similar results are seen in two other studies: at the University of Toronto first year Physics course (Lasry, Watkins, Mazur & Ibrahim, 2013) reports gain values of 34.03–45.02%; in the Physics and Astronomy New Faculty Workshop (Lee, Manju, Dancy, Henderson & Christensen, 2018) the average gain between 40–60% was observed.

So far, the FCI has been administered to countless thousands of students at many universities worldwide. The FCI has not lost its relevance and has been re-examined and as the research by Von Korff et al. (2016) suggests, interactive engagement teaching techniques are significantly more likely to produce high student learning gains than traditional lecturing approach.

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Research Methodology

Background

The study was initiated at University of Latvia. It relies on FCI test as a measurement tool. FCI test consists of two parts: pre-test and post-test composed of multichoice questions and is given at the beginning and end of the course. The measurement is performed by calculating the absolute and relative difference of the results (Hestenes et al., 1992; Lasry et al., 2013). In order to use it at universities of Latvia the FCI test was translated into Latvian and was given to students by several physics' lecturers during the period 2016-2018. During this period experience with the use of the test was gained and language translation inaccuracies were eliminated.

In the first year of the study, FCI pre-test and FCI post-test were carried out at University of Latvia only for one first year undergraduate calculus-based physics course in 2018, and the results were reported at the BalticSTE'19 conference by Cinite and Barinovs (2019, June). After that, the research was continued for students at several universities until autumn 2020, when due to remote training it was decided to not use the FCI test remotely. At this time, the test was administered, and data was analysed for 12 undergraduate student groups at three universities in Latvia involving approximately 450 students in total.

Participants

Students of undergraduate physics courses of three universities: University of Latvia, Riga Technical University and Ventspils University of Applied Science, were involved in this research during the time period 2018–2020. The research includes 445 student's pre-test results.

Not all students performed a post-test, and there were a number of reasons: firstly, for all groups studies started in person, but three out of twelve groups were forced to continue the studies remotely soon after the course started due to the Covid-19 restrictions; and several students did not complete the post-test due to other reasons. The post-test could not be performed if the physical presence of students were not possible during post-test. 344 FCI post-test results were obtained, but only 342 students participated both in pre- and post-test and their results were used to calculate the relative and absolute test score gain in nine groups.

About a quarter of students or 111 students were in calculus-based groups. Participants were approximately 18–20 years old, slightly more than half or 58% of all students were male and 42% female. The classes were taught by 8 lecturers at different levels of the academic ranking: three associate professors, three docents and two lecturers. Three of the lecturers have a doctor (Dr.) degree and other five have a masters (Mg.) degree.

Procedure

The FCI test has been used in a research by the University of Latvia since 2018. Two years before the start of this research, the FCI test was translated into Latvian

https://doi.org/10.33225/BalticSTE/2021.39

and approbated to several groups of students and checked by university teaching staff to prevent translation errors. The original FCI procedure was retained in all research groups: the pre-test was given to students in the first lecture, before starting the course, the post-test was given out at the end of the relevant topic of the mechanics or at the end of a course of mechanics. Both parts of the test were carried out by students in-person, in-classroom, in writing. When it was possible, the course lecturer did not know the test questions in order to prevent the lecturer from preparing the students to correctly answer the specific answers of the post-test.

As in our previous study (Cinite & Barinovs, 2019) teaching effectiveness is characterized by relative learning gain, $\langle g \rangle$, which is defined as the relative change of test results with respect to the maximal possible test result increase from pre-test to post-test

$$\langle g \rangle = \frac{\langle Post \rangle - \langle Pre \rangle}{100 - \langle Pre \rangle},$$

where $\langle Post \rangle$ is group average post-test result and $\langle Pre \rangle$ is group average pre-test result. The relative gain is used since it less depends on the initial knowledge on students and allows to compare groups with different pre-test results. Our calculated gain can be compared to the 0 to 34% average gain $\langle g \rangle$ that has been observed for traditional teaching approach and classes with low student engagement (Hestenes et al., 1992; Lasry et al., 2013).

Research Results

FCI Pre-test Results

Data for all 12 group pre-test results are collected in the Table 1. The group's average pre-test results are in the 18–54% interval of correct answers. Pre-test results for three calculus-based groups are relatively high, in the interval 49–54%; for nine non-calculus-based groups the number of correct answers is between 18% and 37%. The FCI post-test was administered only for nine groups, as three groups started to study remotely after the pre-test. The average relative gain and the average absolute gain of each group was determined for nine groups possessing post-test results.

Table 1
FCI Test Results for Twelve Student Groups, 2018-2020

	N.	Semester	Group average FCI pre-test result	Group average FCI post-test result	Group average absolute gain	Group average relative gain	Learning approach S – student centred, L – lecture centred
			%	%	%	%	
calculus based groups	1	Fall 2018	54	65	11	27	L
	2	Fall 2019	49	81	32	65	S
	3	Fall 2020	51	*continued learning remotely*			
non calculus based groups	4	Fall 2018	37	49	12	23	L
	5	Spring 2019	22	48	26	33	S
	6	Fall 2019	23	54	31	40	S
	7	Fall 2019	25	60	35	47	S
	8	Fall 2019	26	43	17	25	L
	9	Fall 2019	23	61	37	51	S
	10	Spring 2020	26	*continued learning remotely*			
	11	Spring 2020	18	*continued learning remotely*			
	12	Fall 2020	22	48	26	34	S

FCI Gain Results

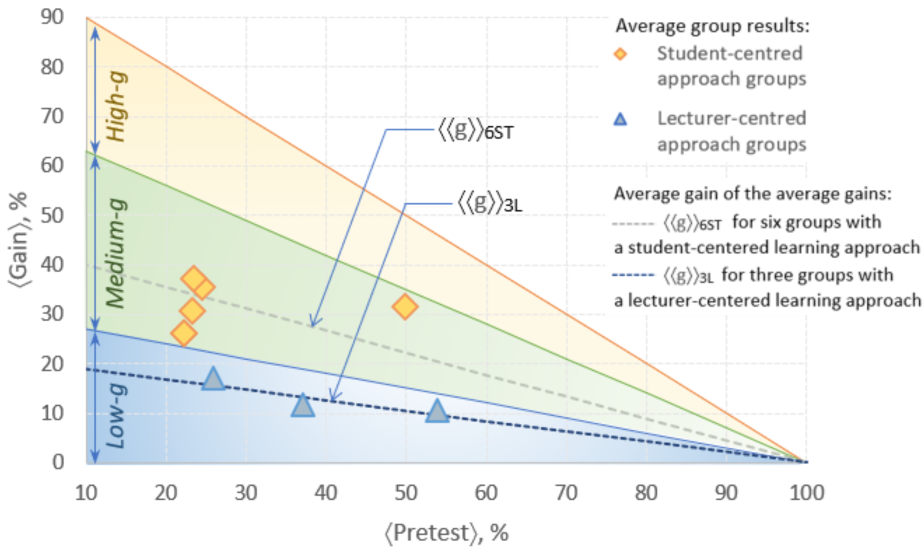
We separately analysed results for two groups: the results of groups where lecturers worked with a lecturer-centred approach and the results of groups where lecturers worked with a student-centred approach. In the student-centred classes 70–80% of time was spent on lectures and 20–30% of time was spent on peer instruction (Mazur, 1997). Lecturer-centred approach classes consisted of information presentation by lecturers followed by solving standard end-of-chapter exercises at different levels of difficulty. Several lecturers in student-centred classes were considerably less experienced than lecturers in lecturer centred classes.

In each of these groups, we analysed the results of calculus-based groups and the results of non-calculus-bases groups separately.

For a calculus-based group with a lecturer-centred learning approach, the group's relative gain is 27%, for a group with a student-centred learning approach average relative gain is 65% which is the highest result in this study. Similar difference of gain in student-centred classes being higher is for non-calculus-based groups. In these groups, a lecturer-centred approach for two groups has resulted in relative gain 23% and 25%, a student-centred learning approach for five groups has yielded 33–51% range for relative gain.

The results are shown in Figure 1, where the idea and visual style of the Figure is adapted from Hake's study (1998). The Figure 1, where different symbols: a blue triangle and a yellow diamond, highlights separately the groups in which the lecturers worked with different learning approaches.

Figure 1
Pre-test Results versus Absolute Gain



Three different colour bars in Figure 1 show the level of the relative gain achievement: 'Low-*g*' result of the groups , a 'Medium-*g*' result , a 'High-*g*' result .

As shown in Figure 1, for those groups where lecturers worked with a student-centred approach, the results are found in the medium-gain area. Regardless of the pre-test results, students were able to achieve a relatively high gain. For lecturer-centred learning approach groups, regardless of the outcome of the pre-test, the gain is placed in a low-achievement area. Among these groups, there is also one calculus-based group with the highest pre-test score of 54%, but only 27% relative gain result.

Normal Distribution and Random Probability of Results

The maximum for probability distribution of correct answers in the pre-test for non-calculus groups is close to 20%, which is close to expected maximum for the random guessing of the test answers in a multiple-choice test with 5 answers for a question. In order to see what part of correct answers could be explained by a simple chance, we have compared the results of the pre- and post-tests with a distribution for random guessing one correct answer out of the five equally possible answers. As can be seen in Figure 2, the pre-test results of non-calculus-based groups with $N = 335$ students remarkably well coincide with the binomial distribution generated by random guessing and both distributions are almost indistinguishable. That suggests that students in non-calculus groups might not possess the knowledge of the basic concepts of physics prior to enrolment at university even if their score is above the average and their higher score might be by a pure chance. On the left side of Figure 2, the centre of distribution of correct answers for students in calculus-based groups is shifted to the right comparing

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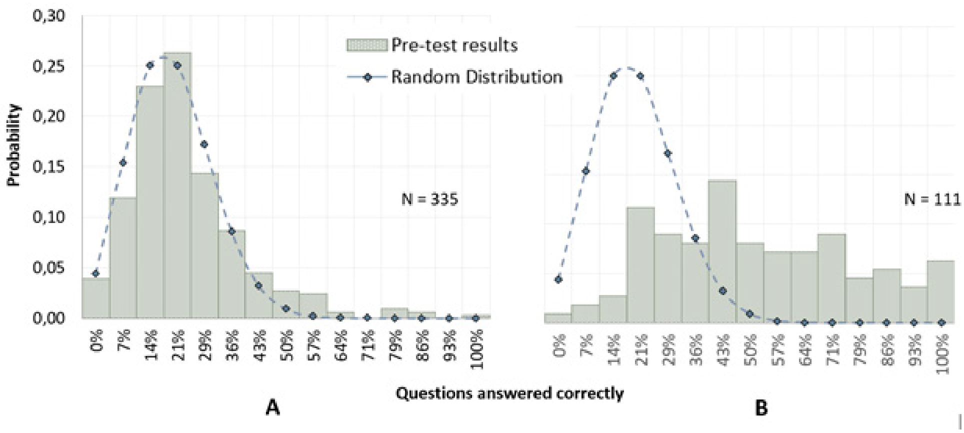
to the probability distribution predicted by random guessing and points to some initial knowledge of students.

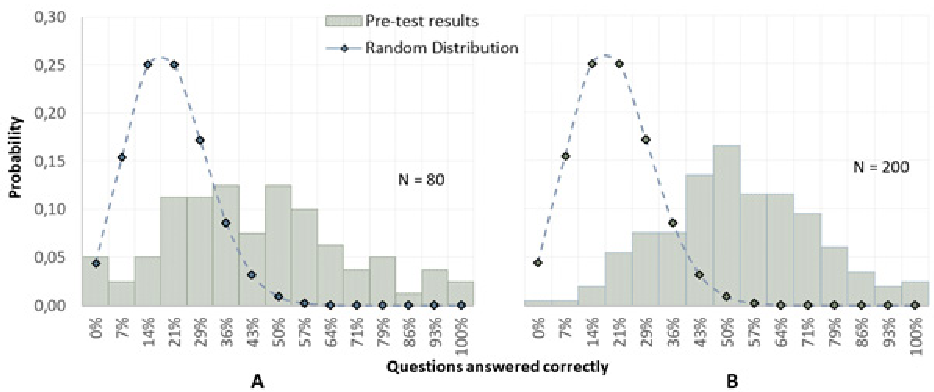
Figure 2
Histogram of the FCI Pre-test Results



Note: A – non-calculus-based and B – calculus-based students; and dashed line of random probability distribution to answer correctly one of the five possible answers for each question.

In the post-test results for all groups the random probability distribution is placed to the left from distribution generated by students' answers, (see Figure 3) showing the growth of student knowledge in both groups.

Figure 3
Non-calculus Groups FCI Post-test Results



Note: A – Lecture centred groups and B – Student centred groups result.

Discussion

The results of this study show that the groups in which lecturers worked with a student-centred approach were able to achieve high relative Gain above 30% despite the low pre-test results for the students. This agrees with the original study of the FCI (Hestenes et al., 1992) that found high relative Gain above 34% achieved by lecturers working with a student-centred approach. Groups, where lecturers worked with a lecturer-centred approach, demonstrated low efficiency, irrespectively to the group's pre-test results. The gain results of this research demonstrate that in universities in Latvia relative gain falls in intervals of 25–65% similar to the studies elsewhere in the world.

The pre-test results for non-calculus-based groups showed that the maximum of the distribution of correct answers is around 20% which is the value obtained by the random guessing of one correct answer of five multichoice test answers. The pre-tests result of calculus-based groups was about 50%. The post-test result confirmed that the growth of students' tests results is closely related to the teaching approach.

In this study the gain as measured by FCI did not depend on lecturer's scientific degree or lecturer's status on an academic pedagogical or academic researcher level. This also has been observed in the study of Hestenes and Halloun (1995).

Conclusions and Implications

The results of the 4-year study on FCI pre-test for 12 undergraduate level student groups have been compiled from 445 students who learned physics in science and engineering courses of three universities in Latvia. To our knowledge, this is the first published FCI study in Latvia and the Baltic states.

FCI pre-test results show the level of students' understanding of the physics basic concepts at the beginning of the studies: the mean pre-test scores for the three calculus-based groups ranged from 49% to 54%, and for the nine non-calculus-based groups ranged from 18% to 37%. Relatively high pre-test scores for calculus-based groups may be explained by students' motivation to study physics, this and other variables should be included in a future research. The distribution of the pre-test results of the non-calculus-based groups is close to the random probability distribution when students correctly guess one of the five possible answers to a question.

The achievement of the student groups as characterized by the relative gain of pre-/post-test results correlates with the lecturer's teaching approach. Groups where training took place through a lecturer-centred approach reached the Relative Gain in the range of 23–27%; two of those groups were non-calculus-based, one calculus-based group.

The result of about 25% reached in lecture-centred learning groups shows that students had been able to reach just a quarter of possible gain on a basic mechanics comprehension test. Those groups also had relatively more students that showed a negative gain. This could indicate a student's confusion in understanding of the basic principles of physics and following guessing of correct answers in the post-test.

Groups where lecturers worked with a student-centred learning approach have shown larger growth in conceptual understanding with the relative gain above 34%. The highest result 65% was observed for the student-centred working calculus-based group.

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The main bulk of studies using FCI is done in United States. This research allowed to verify the FCI in the context of very different education system of Latvia. The research confirmed that in order to provide physics graduates with a good conceptual understanding of physics as measured by FCI, student centred approach is crucial.

Acknowledgements

The authors of this research are grateful to all lecturers of physics courses for their permission to perform this study in their classes. We also thank the lecturers for their interest in the possibilities of student-centred methods in the learning process. We are grateful to the Department of Physics of the University of Latvia for financial support.

Declaration of Interest

Authors declare no competing interest.

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Received: *May 19, 2021* Accepted: *August 01, 2021*

Cite as: Cinite, I., & Barinovs, G. (2021). Increased student performance on physics concept inventory test after student-centred approach in universities of Latvia. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 39-48). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.39

IN-SERVICE SCIENCE TEACHERS' PROFESSIONAL DEVELOPMENT TARGETED TO PROMOTE STUDENT UNDERSTANDING OF CORE SCIENTIFIC CONCEPTS

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Abstract

This review study includes 19 articles from 2016 to 2021 focusing on in-service science teachers' professional development targeted to promote student conceptual understanding. The present study is guided by the following research question: "What characterizes high-quality in-service science teachers' professional development targeted to promote student conceptual understanding?" The review indicates that such classroom practices as modelling, questioning, and arguing from evidence are perspective ways to develop student conceptual understanding in science classrooms. A mixture of input, application, and reflection; long-term involvement of participants; focus on the question how to foster transfer from teacher professional development into participants' everyday work characterize high quality teacher professional development interventions that develop and support inquiry practices. Results suggest that teacher professional development that is sensitive to teacher learning needs is a way to develop student conceptual understanding.
Keywords: *in-service teacher professional development, science teacher education, student conceptual understanding, teacher learning*

Introduction

In the last decades science curricula reforms worldwide have emphasized the importance of fostering pupils' scientific literacy and developing students conceptual understanding through authentic and relevant scientific practices (European Commission., 2011; Eurydice, 2011; Next Generation Science Standards: For States, by States., 2013; OECD, 2006). Concepts and principles are the basic building blocks of scientific knowledge and understanding of a concept is precondition for making complex inferences or accomplishing any scientific work with it (Mi et al., 2020). Therefore, it is decisive for students to attain conceptual understanding about the core ideas of science subjects and build this understanding coherently from K-12.

Teachers and their classroom practice are considered as primal conciliators for the transmittance of reform efforts into student learning outcomes. Therefore, it is critically important to support the development of teachers for the challenge of the reforms (Yang et al., 2018). According to Desimone's (Desimone, 2009) model of effectiveness of teacher professional development (TPD), TPD may increase teacher knowledge and change teacher attitudes and beliefs toward teaching, thereby improving teacher classroom

https://doi.org/10.33225/BalticSTE/2021.49

practice, which in turn results in increased student learning and achievement. This model has been widely accepted, and adopted, in science education. Therefore, high-quality TPD programs are needed to support the development of teachers to adequately align their teaching with the reforms (Yang and Liu, 2020).

Latvia, like other countries, is undergoing a curriculum reform (Nieveen, 2018) that has a focus on 21st century skills, complex use of knowledge, skills, attitudes, and values. In Science subjects and Math, the reformed curriculum includes new goals linked to deep understanding of subject-specific and crosscutting scientific concepts. Thus, it becomes increasingly important to monitor if and how teachers plan and ensure the classroom learning and whether it aligns with the goals of the reform. This then provides information for planning and delivering the necessary TPD support. Still TPD opportunities for in-service science teachers, that are focused to promote student conceptual understanding, are missing (Namsone, 2018). The local context of Latvian science teacher professional development led authors to the current review of recent research focusing on in-service science teachers' professional development targeted to promote student conceptual understanding. Both authors are taking part in the planning, conduction, and evaluation of TPD, so the following research question from TPD organiser point of view arouse: "How the criteria of high-quality TPD manifest into in-service science teacher professional development targeted to promote student conceptual understanding?" The research was aimed to describe the most recent research findings focusing on in-service science teachers' professional development targeted to promote student conceptual understanding.

Research Methodology

Search Criteria

To answer the research question, we conducted a search about pedagogy in the ISI WEB of Science (search undertaken 1. April 2021) using the search strings "teacher professional development" and "student conceptual understanding." The search focused on the years from 2016 to 2021 to cover the most recent research. Intending to obtain an overview of previous research published in international research journals related to teachers' professional development, the authors obtained 73 hits for all the search strings together after narrowing the search down to "education and educational research." Articles were included if they dealt with basic education in primary and secondary school. Exclusion criteria included reviews, articles that dealt with pre-service teachers, special education, higher education, pre-school education, informal learning, and teachers' individual learning. Each of these areas certainly would benefit from separate review studies. In this way, the present study focused on experienced basic education in-service science teacher professional development. Based on the abstracts of the identified articles, we selected a set of 59 articles for thorough reading. After reading all 59 articles, a final set of 19 articles were chosen on the basis of the same exclusion and selection criteria listed above. Altogether, 2 of these articles followed qualitative methods, six employed quantitative research, and eleven involved a mixed-method approach. The published studies mostly came from the USA (15 articles). Single studies came from South Africa, Canada, Saudi Arabia, and Singapore. The selected papers offered both

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breadth and depth, offering insight into the research question of what characterizes high-quality teachers' professional development targeted to promote student conceptual understanding.

Selection of Review Categories

The framework describing high quality PD interventions developed by European STEM Professional Development Centre Network (European Network of STEM PD centres, 2019) was used to examine the articles from a TPD-developer point of view to identify, how the criteria of high-quality TPD manifest into various TPD interventions. According to the framework, high-quality science TPD interventions:

1) involve participants in forms of active learning,
2) provide long-term involvement of participants,
3) are sensitive to and consider participants' learning needs,
4) consider and foster teachers' scientific competence,
5) address knowledge, skills, and attitudes relevant to the curricula,
6) foster the transfer from TPD into participants' everyday work,
7) evaluate the impacts of the TPD.

We structured and compressed the articles by coding and categorizing the texts in selective, open, and axial analysis processes (Strauss and Corbin, 1990, 1998), rendering their essence reportable (Garfinkel, 1967; Sachs, 1992). This selective analysis process enabled selection of a core category; in this study, the core category had been chosen according to the criteria number 5: high quality in-service science teachers' professional development targeted to promote student conceptual understanding.

To define the sub-categories for this review, the criteria number 1 to 4, 6 and 7 of high-quality science TPD interventions were presumed as variables that can be identified in the studies describing TPD interventions and change according to different contexts and goals.

According to the chosen criteria of high-quality science TPD six sub-categories on the same horizontal level were defined: (1) how to involve participants in active learning, (2) how is long-term involvement of participants ensured, (3) how are participants' learning needs considered, (4) how is transfer from TPD into participants classroom practice fostered, (5) how is the development of teacher scientific competence fostered, (6) how are the impacts of the TPD measured.

Research Results

Participant Active Learning

Most of the studies reviewed focused on active participant involvement where teacher-learners engage in inquiry-based input activities followed by reflection about the experience and modelling the application of the learned content. Yang and Liu (2020) highlighted such approach. An input workshop in their TPD program consisted of six parts: (1) a short review, or lesson sharing; (2) a discussion of the focus of the workshop; (3) a first group activity or discussion based on the focus; (4) a second group activity or discussion based on the focus; (5) a presentation by the research team or guest speaker;

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and (6) a debriefing and session evaluation. Not only in the TPD program developed by Yang and Liu (2020), but also in programs developed by Shernoff et al. (2017), Miller and Kastens (2018), Chen et al. (2017), Wilhelm et al. (2018), Drewes et al. (2018) and Murphy et al. (2018) such input workshops were used in pre-schoolyear summer institutes and in-year follow-up sessions. TPD models that combine summer and/or winter institutes with monthly follow-up sessions and independent implementation of learned into practice between the follow-up sessions have shown satisfaction between teacher-participants (Shernoff et al., 2017) and positively impacted student conceptual understanding (Miller & Kastens, 2018; Wilhelm et al., 2018). Binmohsen and Abrahams (2020) and Yoon et al. (2020) have investigated how programs developed according to similar TPD model have been conducted online. Their findings suggest that online TPD can be as effective as, and in certain places more effective than, the face-to-face TPD.

Yoon et al. (2020) distinguished social ties, which can be developed through discussion boards or experience and resource sharing, as a key aspect of online TPD. Another approach that enables active involvement of participants in TPD is collaborative action research (CAR). Both Yin and Buck (2019) and Goodnough and Goodnough (2018) investigated how CAR can be used in TPD that is focused on implementation of classroom practices that promote student conceptual understanding. Both groups of authors concluded that CAR approach in TPD requires additional support to the teacher-learners, who can border with individual mentoring, especially when novice teachers take part in CAR.

Long-term Involvement of Participants

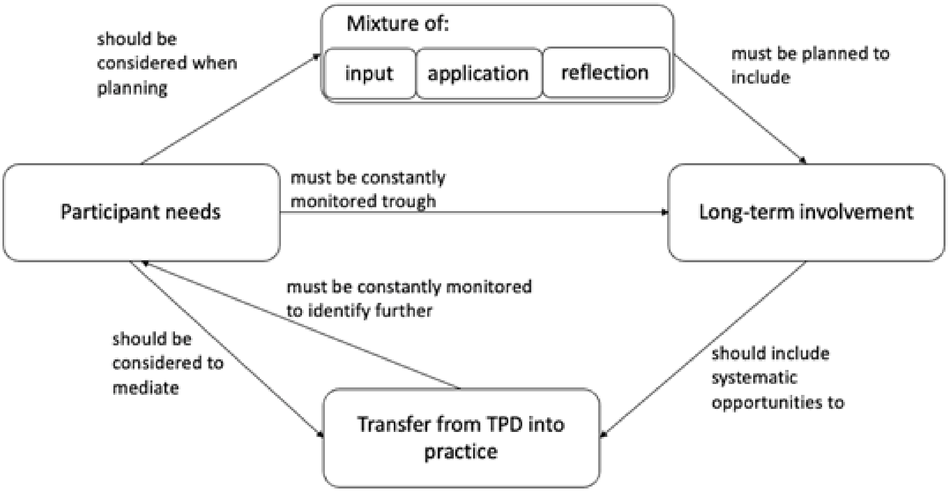
11 of 19 studies reviewed included TPD interventions that lasted for more than 1 year. TPD interventions carried out by Yang and Liu (2020) and Chen et al. (2017) can be mentioned as the most longitudinal, lasting 5 and 4 years respectively. In both programs the long-term participant involvement was ensured through the summer institute – regular follow-up session model. Through participant questionnaire Yang and Liu (2020) identified an interconnection between teacher summer placement in research facilities and teacher-participant long-term involvement in TPD. Participant questionnaire answers indicated that the authentic experiences of scientific practice that teacher-learners experienced served as motivators to implement and teach the elements of these practices in their science lessons.

Participant Learning Needs

Only few of the reviewed studies describe the identification and consideration of participant learning needs. An example of such practice was described by Miller and Kastens (2018). The authors investigated how implementation of dynamic physical models in classroom practice impact student conceptual understanding. The TPD included in the research started with teacher-participant interviews where in the curricula they teach they see the right fit for extended modelling practice. The further TPD program and implementation in classroom practice focused on learning units identified by teachers. The authors reported active teacher involvement in the two years of the TPD program and increase in student conceptual understanding regarded to the curricular topics, where teachers implemented extended use of dynamic physical models. Another example of the evaluation of teachers learning needs was described by Stott (2020). Before a TPD intervention to promote conceptual understanding about chemical equilibrium, the author carried out a belief questionnaire and a biographical survey. Data analysis led to the identification of teacher sub-groups and development of two different TPD interventions. One – to foster the keystone practices to promote student conceptual understanding, the other – to focus on more complex classroom practices that promote student conceptual understanding.

The discussion section of almost all the articles reviewed mentioned participant needs as an area for future research. Logical connections between consideration of participant needs and mixture of input, application, and reflection; long-term involvement of participants and transfer from PD into participants' everyday work can be identified (Figure 1).

Figure 1
The Identified Connections between Criteria of High-quality Science TPD



The scheme, presented in Figure 1, doesn't include the criterion that high-quality science TPD interventions must foster teacher's scientific competence. Learning science, the understanding of concepts can't be isolated from scientific skills. Understanding of concepts can be gained and assessed through use of science skills. The combination of understanding with skills leads to a complex outcome which is a step in developing scientific competence.

Transfer from TPD into Participants Classroom Practice

Various ideas how to foster the transfer of the ideas, knowledge and pedagogical practices obtained in the TPD interventions can be highlighted in the reviewed articles. The studies conducted by Murphy et al. (2018), Yoon et al. (2020) and Binmohsen

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and Abrahams (2020) described ready-to-use classroom resources as mediators for the implementation of classroom practices that promote student conceptual understanding into everyday work. In contrast Shernoff et al. (2017) used writing of curricular unit plans and lesson plans as a method to foster the transfer from TPD into participant's everyday work. The authors report various outcomes as some teacher-learners struggled with appropriate implication of classroom practices that promote conceptual understanding in lesson and unit plans, but some – with implementation of aligned assessment strategies. Two case studies conducted by Longhurst et al. (2017 & 2021) investigated the mediators that help teachers transfer TPD into everyday work. In both studies the authors studied sub-samples of the teachers who managed this transfer best. The data collected in this investigation indicated that the personal construction and modification by teachers participating in TPD may be critical in achieving high levels of appropriation of instructional pedagogies provided during TPD interventions. Factors that influence appropriation of professional development and inquiry strategies include opportunities for personalized paths to appropriate conceptual or practical tools, planning for intentional adaptation allowing teachers to develop ownership attributes of pedagogical tools of instruction, and the support or creation of trusting cultures of learning where teachers develop long-term support systems. Miller and Kastens (2018) came to similar conclusions in their study about implementation of modelling practice to promote student conceptual understanding. The authors mention the deep engagement with modelling practice within the context of participant subject matter; adequate time and support to generate lessons that integrated the proposed strategies while maintaining each teacher's autonomy; TPD interventions built around models that they were already using as key strengths of the TPD program.

Development of Teacher Scientific Competence

Conceptual understanding is interrelated with skills and beliefs that form scientific competence. Such scientific skills as argumentation (Cavlazoglu and Stuessy, 2017; Chen et al., 2017; Fishman et al., 2017; Murphy et al., 2018; Osborne et al., 2019), modelling (Miller and Kastens, 2018; Wilhelm et al., 2018) can be used as classroom practices to acquire conceptual understanding. Conceptual understanding is vital to form beliefs who can later form into behaviours and actions that help to solve complex global socio-scientific issues (i.e., climate change) (Drewes et al., 2018). Also, student behaviour and actions they take to solve socio-scientific issues can be used in tandem with other practices to assess student conceptual understanding.

Evaluation of TPD Impacts

Most of the studies reviewed use common methods to measure how TPD impacts participant practice. To uncover how the TPD impacted teachers practice mixed-method approach is common in the reviewed studies. Most of the studies include different combinations of such well-known TPD evaluation methods as semi-structured interviews (Mulvey and Bell, 2017; Yin and Buck, 2019), lesson observations (Daane et al., 2018; Drewes et al., 2018; Yin and Buck, 2019), participant and student questionnaires (Binmohsen & Abrahams, 2020; Yang & Liu, 2020), student conceptual understanding

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tests (Drewes et al., 2018; Murphy et al., 2018; Yang & Liu, 2020), expert observations (Daane et al., 2018), and participant lesson plan analysis. Still there were few examples of novel methods of TPD impact evaluation. Cavlazoglu and Stuessy (2017) investigated changes in science teachers' conceptions about earthquake engineering. One of the methods authors used to determine the changes in teacher-participant macro- and micro-level knowledge after TPD intervention was teacher concept map analysis. Sherwood and Sherwood (2020) examined shifts in teacher perceptions of classroom instruction that promotes conceptual understanding before and after TPD experience. Visual research methods were used to collect qualitative data (teacher drawings), which were analysed and interpreted using quantitative methods, and compared with content analysis of teachers' written text.

Conclusions

The analysis of the articles reviewed showed that almost all TPD interventions were designed according to criteria of high-quality science TPD interventions (European Network of STEM PD centres, 2019). A TPD model that provides interplay of input, application and reflection was summer institute followed by monthly follow up sessions during the school year with time for practice and classroom implementation or lesson studies between them. Another TPD model that can provide this complex interplay is collaborative action research.

Both TPD models lead to a logical connection between input, application and reflection and long-term participant involvement as full implementation of TPD interventions developed according to the models takes at least one school year. Both models also include independent teacher practice followed by reflection which is a way how to foster the transfer from TPD to participant's everyday work. Personalized learning paths, planning for intentional adaptation and the support or creation of trusting cultures of learning are some mediators that can develop teacher-learners ownership of the learned contents. The evaluation of TPD impacts must include mixed-methods approach, combining both qualitative and quantitative methods to evaluate how TPD has impacted teacher knowledge, perceptions, classroom practice and student outcomes.

Acknowledgements

This research is supported by the Latvian Council of Science project "Innovative solutions in assessing teacher competencies for personalized professional learning", No. lzp-2019/1-0269.

Declaration of Interest

Authors declare no competing interest.

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Received: *May 23, 2021*   Accepted: *August 04, 2021*

Cite as: Greitāns, K., & Namsone, D. (2021). In-service science teachers' professional development targeted to promote student understanding of core scientific concepts. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 49-58). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.49

PROCEDURE FOR ASSESSMENT OF THE COGNITIVE COMPLEXITY OF THE PROBLEMS WITH A LIMITING REACTANT

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Abstract

Mathematical calculations are an important part of chemistry. Those problems are difficult for students, especially if the task is set with a limiting reactant. The aim of this study was development of a Procedure for evaluation of cognitive complexity of the Stoichiometric Tasks with a Limiting Reactant. The procedure created included an assessment of the difficulty of concepts and an assessment of their interactivity. As a research instrument for assessing performance, the test of knowledge was specifically constructed for this research. Each task in the test was followed by a seven-point Likert scale for the evaluation of the invested mental effort. The research included 58 upper-secondary students. The validity of the procedure was confirmed by a series of regression analyses where statistically significant correlation coefficients are obtained among the examined variables: students' achievement and invested mental effort from cognitive complexity (independent variable).

Keywords: *chemistry education, stoichiometry, problem tasks, achievement, mental effort*

Introduction

Stoichiometry is one of the key areas of chemistry. The numerical parameters of a chemical reaction, the concentration of reactants, the amount of substance, as well as the basic parameters of chemical kinetics and equilibrium are calculated based on stoichiometric relations (Hanson, 2016). In a chemical reaction, two or more reactants react in constant molar relation - they react stoichiometrically. For example, hydrogen molecules react with oxygen molecules in a reaction where water molecules are formed as the product in a stoichiometric molar ratio of 2: 1. One of the fundamental concepts in stoichiometry is the calculation of the quantity, volume, number of particles or the mass of the products of a chemical reaction between two reactants where one of the reactants is a limiting reactant (Sostarecz & Sostarecz, 2012).

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In chemical reactions - a limiting reactant, i.e., a limiting reagent, is a reactant that first reacts all in a chemical reaction, i.e., it is "consumed" first (Olmsted, 1999). A limiting reactant stops a chemical reaction when it fully reacts and therefore determines the amount of a formed reaction product (González-Sánchez et al., 2014). The tasks with limiting reactants are one of the most difficult tasks in stoichiometry (Gulacar, et al., 2013). Students often use algorithms when they solve problems with limiting reactants. They often calculate the amount of products for both reactants, and then they choose the one that produces fewer reaction products as the limiting reactant (Toth, 1999). Students do not understand the definition of a limiting reactant, what it represents, and how they decide on it. Students define a limiting reactant as the reactant with the smallest number of atoms (Marais & Combrinck, 2009). By a term limiting reactant, they mean the reactant that needs to be quantitatively higher to react completely with another reactant (Kashmar, 1997), i.e., the limiting reactant is the one that has fewer moles in the initial system (González-Sánchez et al., 2014). In a study by Dahsah and Kol (2007), students consider the reactant expressed in the smallest unit of mass the limiting reactant, without taking into account the amount of substance and the molar ratio. In the same research, some students claim that if both reactants are not present in a stoichiometric amount, there is already a limiting reactant, the chemical reaction will not happen, and no products will be formed.

The relation between the reactants which is not 1: 1 is confusing for students, even when the reactants are expressed in moles (Kalantar, 1985; Hanson, 2016). Similar results were found (Dahsah & Coll, 2007), where students always took a mole ratio 1:1 between the reactants regardless of the coefficients in a chemical reaction equation. In a study by Olmsted (1999), this result was previously confirmed in a problem with a limiting reactant where the ratio of coefficients was 3:2. Only 30% of students solved the task successfully although the reactants were given as the amounts of substances. The errors found in his research were that students did not take into account stoichiometric coefficients, and they used the wrong algorithm for calculating the limiting reactant. Haidar (1997) and Hanson (2016) have even concluded that students take molar ratios into account when they calculate substances if substances are given in terms of mass units. Hanson (2016) also noticed that there were a misunderstanding and a misuse of terms for mass, quantity, and molar mass in calculations in the problem-solving tasks with limiting reactants. Coefficients and indexes in chemical formulas are confusing for students in a chemical equation, and therefore a common cause of errors in calculations is that students misuse coefficients and indexes in chemical formulas (Chandrasegaran et al., 2009; Mulford & Robinson, 2002). Thus, Huddle and Pillay (1996) observed that a limiting reactant from the students' perspective was the reactant with the smallest stoichiometric coefficient. In research by BouJaoude and Barakat (2000), students chose a limiting reactant arbitrarily without a logical explanation, although they usually opted for the reactant expressed in units for the amount of substance. In their next research, students quoted the fact that it was easier to calculate using moles as the main reason why they chose the reactant expressed in moles (BouJaoude & Barakat, 2003). In problems, students choose a limiting reactant by observing which of the reactants contains more atoms of the elements of the desired reaction product (Wood & Breyfogle, 2006).

In addition to all the misconceptions, students' difficulties arising during the resolution of limiting reactant stoichiometry problems are caused by the complexity of

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the tasks themselves. Namely, problem-solving tasks contain a large number of chemical concepts that are interconnected by different relationships, which imposes a cognitive load on students (Kalyuga, 2009).

While being processed in the working memory, new information is recombined and brought into connection with already acquired knowledge and then stored as schemas in the long-term memory. The working memory becomes overloaded if it simultaneously processes more information. That is a cognitive load (Kalyuga, 2009). The cognitive load is a multidimensional construct consisting of three measurable components: a mental workload, mental effort, and performance. The mental load is imposed by the teaching parameters, the mental effort is determined by the available capacity of the working memory assigned to solve a task, and the performance is the student achievement. According to Sweller et al., (2011), the self-assessment of mental effort is the most sensitive component in assessment of the differences in the cognitive load imposed by different teacher's instructions. One of the cognitive load indicators which have been used as an objective measure recently is cognitive complexity (Harris et al., 2013; Raker et al., 2013).

Bieri (1955) introduced the term cognitive complexity that reflects a high degree of differentiation of the system of the constructs that individuals use. Concerning the cognitive complexity of a task, the key component is its characteristics. These characteristics can be dimensioned by the experts' estimation. They can evaluate the requirements of the task from the aspect of the cognitive load theory. Recent studies have shown that cognitive complexity can be used to predict student achievement in assignments and invested mental effort (Knaus et al., 2011; Raker et al., 2013).

Different tools have been developed - Rubrics for estimating the cognitive complexity of problems in chemistry (Knaus et al., 2011; Raker et al., 2013). The developed Rubrics were created based on the theory of complexity (Goldreich, 2008), which defines a system of more related concepts, and the theory of cognitive load (Sweller et al., 2011), which defines interactivity among the concepts in a task. The use of the Rubric provides an easy way to quantify the cognitive demands of a problem (Knaus et al., 2011; Raker et al., 2013). To assess the cognitive complexity of tasks, experts assess the number of elements, i.e., the concepts needed to solve a test task. They also assess the difficulty of each concept from students' perspective as easy, medium, and difficult. When all the concepts needed for solving the task are recorded, the complexity of the task is determined with the use of the Rubric. After determining the difficulty rating of the concept, interactivity is calculated. Interactivity increases the cognitive complexity of the task when students need to use the interdependence of the components to solve the task. Interactivity is assessed as insignificant, basic, and complex. Further development of the Rubrics for the cognitive complexity rating is presented in the works of Horvat et al. (2016, 2017, 2020).

Research Problem

So far, the Rubrics for the cognitive complexity rating in several domains of chemistry have been developed. All of them show satisfactory coefficients of the correlation between cognitive complexity and student performance, and between cognitive complexity and mental effort. However, there was a need for the correction

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due to the specificity of domains in all the Rubrics. One of the many concepts present in stoichiometry problems that further complicate them is the concept of a limiting reactant. Problem-solving tasks with a limiting reactant are characterized by high complexity, and therefore they are often confusing for students. In this paper, a Procedure for assessment of the cognitive complexity of stoichiometric tasks with a limiting reactant has been developed.

Research Focus

This research aim was to develop and validate the procedure for determining the cognitive complexity rating of the stoichiometric tasks with a limiting reactant. The specific research objectives for determining a numerical rating of cognitive complexity were:

- Construction of a Table for assessing the difficulty of concepts and their interactivity needed for the assessment of cognitive complexity of chemical technology problem-solving tasks;
- Determination of cognitive complexity of test tasks using a combination of a constructed Table for assessing the difficulty of concepts with a cognitive complexity rating rubric proposed by Knaus et al. (2011);

From specific research objectives research questions for validation of the procedure were created as follows:

- Is there a statistically significant correlation relationship between the students' performances and the numerical rating of the cognitive complexity of problems, and
- Is there a statistically significant correlation relationship between the invested mental effort and the cognitive complexity.

Research Methodology

General Background

The research was conducted in May 2017, during the second semester of the school year 2016/2017. Students solved the test of knowledge with 7 tasks. With the test of knowledge, a collection of students' achievements and a collection of students' invested mental effort were collected. Students' achievements and invested mental effort were dependent variables, and previously determined cognitive complexity was an independent variable. Validation of procedure and research instrument was confirmed with basic statistics parameters, descriptive statistics, and correlation coefficients.

Sample

The total sample of this research consisted of two classes made up of 58 students from the Gymnasium in Prijepolje. According to the Curriculum (The Institute for the Advancement of Education, 2013), the students of this school attend chemistry classes during their four-year schooling. According to the Curriculum, general chemistry is studied in the first grade, inorganic chemistry with laboratory exercises in analytical

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chemistry is studied in the second grade, organic chemistry is studied in the third grade, while the basics of biochemistry are studied in the fourth grade.

The students who participated in this study attended the first grade and were aged 15-16. According to the grades in chemistry at the end of the first semester, the structure of the students who were included in the sample for this research was the following:

- 18.96% of the respondents had a grade 2 in chemistry at the end of the first grade,
- 32.76% of the respondents had a grade 3 in chemistry at the end of the first grade,
- 37.93% of the respondents had a grade 4 in chemistry at the end of the first grade and
- 10.35% of the respondents had a grade 5 in chemistry at the end of the first grade.

The respondents belonged to the urban population of different socioeconomic statuses, and they voluntarily joined the research. All students voluntarily participated in the research. Informed consent was obtained from students and school administration.

Instrument and Procedures

The Knowledge Test was specially designed for this research. The students had 45 minutes (one school class) to solve the test. The respondents studied all the concepts present in the test tasks in chemistry classes. The test created for this research contained 7 tasks. The students got one point for each correct task, so the maximum possible score on the test was 7 points. The incomplete tasks were not taken into consideration.

In addition to the achievement, the test also measured the mental effort that a student invests while solving the task. The assessment of the invested mental effort was measured by a subjective technique with the application of the 7-point Likert scale. After each completed or uncompleted task, the students were asked to assess their mental effort by selecting an appropriate descriptive grade on the scale. During the statistical analysis of the results, the descriptions were numerically coded from "extremely easy" – numerical value 1 to "extremely difficult" – numerical value 7.

To ensure objectivity in the estimation of cognitive complexity, the Table for the assessment of the difficulty of concepts and the estimation of their interactivity in problem tasks with a limiting reactant has been developed. The difficulty of the concepts is also estimated by the Rubric developed by Knaus et al. (2011). Concepts are rated according to their difficulty as easy, medium, or difficult. Table 1 describes the Table for estimating the difficulty of the concepts and their interactivity in the stoichiometric problems with a limiting reactant.

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Table 1

The Table for the Assessment of the Difficulty of the Concepts and the Estimation of Their Interactivity in the Stoichiometric Tasks with a Limiting Reactant

A CHEMICAL EQUATION WITH GIVEN QUANTITATIVE RELATIONS	
The ratio of the reactants, the ratio between the given and the required substance is 1: 1	Easy
The ratio of the reactants, the ratio between the given and the required substance is 1:X (X≧2)	Medium
The ratio of the reactants, the ratio between the given and the required substance is X: Y (X≧2; Y≧2 X≠Y)	Difficult
A LIMITING REACTANT	
The reactants, the given and the required substances are given in a formula about the amount of substance	Easy
The reactants, the given and the required substances are given in the units of mass	Medium
The reactants, the given and the required substance are given in the ratio amount: mass or mass: amount	Difficult
THE INTERACTIVITY OF THE CONCEPTS	
The task contains up to 2 concepts	0
The task contains 3 concepts	1
The task contains over 3 concepts	2

The concept of *a chemical equation with given quantitative relationships* was chosen because the understanding of quantitative relationships among the participants in a chemical reaction is a key step in solving stoichiometric problems (Robinson, 2001). This problem is particularly pronounced if the quantitative relationship between the given and the required substance in the chemical equation is not 1: 1 (Dahsah & Coll, 2007; Hanson, 2016). Students sometimes choose the ratio 1: 1 in the problems with a limiting reactant regardless of the ratio of the stoichiometric coefficients of the participants in a chemical reaction, (Olmsted, 1999). If the given and the required substance are expressed in the same physical entity, the concept is considered easy (Robinson, 2001). If the given and the required substance are given in the same physical entity in the Rubric for the rating of the concepts that are present in stoichiometric problems, the concept is considered easy, regardless of whether the substances are expressed as the amount of substance, a mass, the number of particles, etc. (Horvat et al., 2016). However, it is documented that students achieve better results if the given and the required substance are expressed in the units of the amount of substance than if they are expressed in the units of mass (Astudillo & Niaz, 1996). So, the concept of a limiting reactant is the easiest if the substances are expressed in moles. A concept is a medium difficulty if the substances with which the calculations are made are given in the units of mass, and difficult if the given or the requested substance is expressed in the unit of quantity and the other substance is expressed in the mass unit.

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Interactivity is evaluated based on the number of concepts in the task. If one concept is represented in the task, interactivity is evaluated with a value of 0. If the task contains two concepts, interactivity has value 1, and if the task contains three or more concepts, interactivity is evaluated by a numerical value 2.

Data Analysis

The quality of the test was evaluated by pre-test and post-test quality assurance parameters. Pre-test quality assurance parameters are determined by experts, whose narrow field of study is the methodology of chemistry teaching, as well as chemistry teachers in secondary schools. The test was assessed as valid based on the compliance of the tasks with the valid curriculum and the recommended textbooks. The experts assessed the tasks on the Test as diverse, with clearly defined requirements and meaningful sentences in compliance with language rules. Post-test quality assurance parameters are defined as basic statistical parameters: reliability coefficients, task discrimination indexes, the index of the discriminative property of a test, task difficulty indexes and test difficulty indexes.

The obtained results were analyzed using IBM SPSS Statistics 22 software program.

Research Results

Tasks of different levels of cognitive complexity were used in this research. The complexity of the tasks depends on the concepts which are present in the task and defined in Table 1. All tasks are complex problem-solving tasks that include two sub-problems: determining the limiting reactant and calculating the required substance. The principle of using this Table is simple and objective. The procedure for calculating the rating of cognitive complexity is presented in the following example (Task number 1 in the Test): *7.3 grams of hydrogen chloride and 4 grams of ammonia were mixed in the reaction vessel. The mentioned gases react according to the following reaction*:

$$HCl_{(g)} + NH_{3(g)} \rightarrow NH_4Cl_{(s)}$$

Calculate how many grams of ammonium chloride is obtained in this reaction.

The first phase involves determining the limiting reactant and the second phase involves calculating the mass of the formed product. The task contains the four concepts presented in Table 1. In the first phase, the limiting reactant is determined based on the data from the text of the task and the chemical reaction equation. The quantitative ratio between the reactants is 1: 1, and the reactants are given in the units of mass. The limiting reactant is determined based on the chemical reaction equation and the molar masses of the reactants. Using the Table for assessing the difficulty of the concepts and their interactivity in stoichiometric tasks with limiting reactants, their difficulty is estimated. The following concepts are present in this task:

- The stoichiometric ratio of the reactants is 1:1 - The chemical equation concept with the given quantitative relationships which is "easy";
- The stoichiometric ratio of the reactant to the reaction product is 1:1 - The concept of a chemical equation with the given quantitative relationships which is "easy";

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- The reactants are expressed in the units of mass - The concept of a limiting reactant that is "medium" difficulty;
- The reactant (the given substance) and the reaction product (the required substance) are expressed in the units of mass – The concept which is "medium" difficulty;
- The task contains 4 concepts – Interactivity has a value of 2.

Using the Rubric developed by Knaus et al. (Knaus et al., 2011), gives the total numerical rating of cognitive complexity of task number 1 in the test, which is 7.

Table 2
Numerical Rating of Task Number 1

The difficulty of the concept	Number of concepts	Numerical rating
Easy	2	2
Medium difficult	2	3
	Interactivity:	2
	Total rating of cognitive complexity:	7

As in this case, the numerical rating of the cognitive complexity of other test tasks is calculated. The values are shown in Table 3.

Table 3
Numerical Rating of Cognitive Complexity of Test Tasks

Task number	A numerical rating of cognitive complexity
1	7
2	7
3	8
4	6
5	10
6	10
7	9

The test used in this study showed good metric characteristics. Reliability was calculated as a measure of internal consistency and expressed as a Cronbach's coefficient α which valued .65 for the achievements, and .73 for self-estimated mental effort, which indicates good reliability (Jonsson & Svingby, 2007). The task's difficulty index ranges from 13.79% to 96.55% (the average value is 49.51%, which makes the test moderately difficult). The value of the difficulty index of two tasks is less than 25%, which makes them difficult, whereas the difficulty index value of one task is higher than 75%, which makes it an easy task (Towns, 2014). The values of the discrimination index range from .07 to 1 (the medium value is .59 which represents an excellent discrimination index of the test). Six tasks have an excellent index of discrimination which is higher than .4 (even 3 tasks have an index of discrimination higher than .94), whereas only one task has a poor index of discrimination (.07), so it should be revised for future use.

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The basic statistical parameters of the test are shown in Table 4.

Table 4
Descriptive Statistics for the Students' Performance and Mental Effort

Parameter	Students' performance[1] (*N*=58)	Students' ratings of mental effort[2] (*N*=58)
Average	3.46	3.80
Standard deviation	1.71	.90
Standard skewness	-.12	.67
Standard kurtosis	-1.03	.12
Minimum	0	1.86
Maximum	7	6.14
Range	7	4.28

[1] Students' performances could range from 0 to 7.[2]Possible ratings for invested mental effort could range from 1 to 7: extremely easy (1) to extremely difficult (7)

The values of the standard skewness and kurtosis for the performance and the invested mental effort indicated that in both cases a normal distribution was presented. Additional Shapiro-Wilk's test did not confirm the assumption of the normal distribution of students' performances (F=.20; p<.05) and students' mental effort (F=.16; p<.05).

The validation of the test was performed by Spearman's correlation which refers to the observation of the relation between the students` performances and self-estimated mental effort. The graphic dependence and the statistical parameters of regression analysis are shown in Figure 1 and Table 5.

Figure 1
The Correlation of the Students' Performance with the Students' Ratings of the Invested Mental Effort

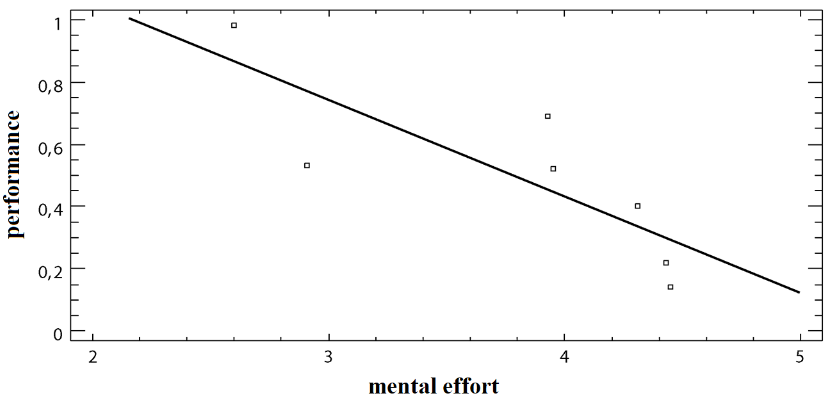

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Table 2
The Statistical Parameters of the Regression Analysis of the Students' Performances and the Students' Ratings of the Invested Mental Effort

Parameter	Value
The correlation coefficient	-.58
p-value	.02
Equation	Performance = 1.67 - .31×ME

This dependence describes a moderate correlation (r_s=- .58; p=.02). P-value is less than .05, which indicates that there is a statistically significant correlation between measures of mental effort and performances at the 95% confidence level. The existence of a significant correlation between performance and mental effort has already been confirmed in the studies about the dimensioning cognitive complexity of the problems (Knaus et al., 2011; Raker et al., 2013; Horvat et al., 2016; 2017; 2020).

Procedures for assessing the cognitive complexity of problem tasks are usually validated by combining with measures of students' performances and measures of mental effort (Knaus et al., 2011; Raker et al., 2013; Horvat et al., 2016; 2017; 2020).

In the first phase, the regression analysis of the dependence of students´ performances on the estimated cognitive complexity. As the distribution of performances and mental effort did not satisfy the normal distribution criterion and since the performance values can only be zero or one, it was done with biserial correlation analysis. The results of the analysis are tabulated in Table 3. The dependence of the numerical rating of the cognitive complexity from the students' performances on test tasks (406 items) was observed.

Table 6
Statistical Parameters of the Regression Analysis of Students' Performance and the Cognitive Complexity

Parameter	Value
The correlation coefficient	- .37
p-value	$p < .001$
Equation	Achievement = 1.64 - .13×CC

The coefficients obtained by the regression analysis (r_{bs} = -.37; $p < .05$) indicate that there is a moderate but statistically significant correlation between the dependent and the independent variables (Evans, 1996). The negative value of the correlation coefficient shows that the increase in the cognitive complexity of the problem results in performance decreases.

The second phase of validation of the procedure for the assessment of cognitive complexity of the tasks with limiting reactants is a correlation analysis of the dependence of self-invested mental effort on the rating of the cognitive complexity of the tasks. Since mental effort does not satisfy normal distribution, the Spearman's ρ correlation

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coefficient was determined. Statistical parameters and graphic dependence are shown in Table 7.

Table 7
Statistical Parameters of the Regression Analysis of the Student's Self-invested Mental Effort and the Cognitive Complexity

Parameter	Value
The correlation coefficient	.54
p-value	$p < .001$
Equation	Mental Effort = -.35+.47×CC

The correlation coefficient (r_s =.54) and the p-value (p<.05) indicate a moderately strong statistically significant correlation between the mental effort as a dependent variable and the numerical value of the cognitive complexity rating as an independent variable.

Discussion

The test used in this research had good statistical parameters. The average achievement of students was 3.46, which means that students could solve a minimum of three tasks. The average value of students' mental effort on the test was 3.80. According to the 7-point Likert scale, the test was "neither easy nor difficult".

The validity of the procedure was confirmed with a correlation between students' performances and the average value of students' self-invested mental effort from the numerical rate of cognitive complexity. The positive value of the coefficient of correlation indicates that students invest a higher mental effort to solve the task with increasing cognitive complexity. At the same time performance decreases. This is consistent with the results of Pollock et al., (2002). Since the information is selectively processed during the process of solving the task, it is necessary to optimize its cognitive complexity when designing the task (Halford et al., 1998). Cognitively more complex tasks impose a greater mental load on the working memory of respondents and condition lower student achievement (Campbell & Gingrich, 1986).

The rating of the cognitive complexity of the examined tasks ranges between 6 and 10. The first and second tasks have the value 7 of cognitive complexity, where the average achievement is .97 and .53. A strikingly significant difference in the achievement is the consequence of the strategy for solving stoichiometric tasks that is favorable in the used textbook literature which favors the comparison of masses (Nikolajević & Šurjanović, 2015). Namely, in the first task, the reactants are expressed in mass units, and in the second task, their amounts in moles are given. A similar situation has been noticed in two of the most difficult tasks. The rating of the cognitive complexity of the fifth and sixth tasks is the same - 10. The average students' achievements in these tasks are .69 and .22. And in this case, student achievement is the highest in the fifth task in which the participants of the reaction are expressed in the mass units. It can be noted that students manipulate the mass more effectively than the moles in tasks with limiting reagents, which is unexpected. Olmsted (1999) noted that students solved problems with a limiting reactant with the strategy used by the teacher, or that is recommended in textbooks. Namely, the students insisted on comparing the mass of the reactants rather than on comparing the amounts of the substances.

Conclusions and Implications

The basic research task was to create a procedure for assessment of the cognitive complexity of stoichiometric tasks with a limiting reactant. To accomplish this, a Table for assessing the difficulty of the concepts and their interactivity was constructed. Thus, a valid procedure was obtained for assessing the cognitive complexity of stoichiometric problems with a limiting reactant.

The validity of the Procedure was confirmed by a series of regression analyses of the dependence of students` performances and their assessment of invested mental effort from the cognitive complexity. High values of correlation coefficients were determined: -.37 for the dependence of achievement-cognitive complexity and 0.54 for the dependence of mental effort-cognitive complexity. The results of these analyses are presented in graphical and tabular form and the form of equations of regression analysis.

The process developed in this research should help teachers in the design of the tasks with a limiting reactant of different levels of cognitive complexity. By gradually developing the complexity of problem-solving tasks with a limiting reactant, the teacher can develop problem-solving strategies, taking care of the mastered concepts. This can affect the cognitive development of each student. The design of the tasks of different levels of cognitive complexity is a way to estimate the learning outcomes better and to determine cognitive load using the measures of mental effort.

The limitation of this survey is a sample of respondents. Also, when literature is concerned, a small number of stoichiometric tasks with limiting reactants are present in it and they are exclusively expressed in the units of mass. Therefore, students' mistakes and increased amount of their mental effort come from an algorithmic approach to solving these problems, which also arise from the teacher's strategy.

The implications for further research in this area are the design of problem-solving assignments in which the reactants will be expressed, in addition to the units for mass and the quantity of substance, in another unit (the number of particles, volumes, etc.).

Acknowledgments

The authors acknowledge the financial support of the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 451-03-9/2021-14/ 200125)”.

Declaration of Interest

Authors declare no competing interest.

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Received: *May 26, 2021* Accepted: *August 09, 2021*

Cite as: Horvat, S. A., Rodic, D. D., Rončević, T. N., Babić-Kekez, S., & Trifunović Horvat, B. (2021). Procedure for assessment of the cognitive complexity of the problems with a limiting reactant. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 59-73). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.59

LAWSON CLASSROOM TEST OF SCIENTIFIC REASONING AT ENTRANCE UNIVERSITY LEVEL

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Abstract

The Lawson classroom test of scientific reasoning is a quite popular and widely used tool that measures the level and development of the student's scientific reasoning skills. In this contribution, the results of this test for the N=446 students of the Faculty of Science Palacký University Olomouc from the years 2018–2020 at the beginning of their study were analysed. Calculation of the standard characteristics of the test items (difficulty index, discrimination index and point biserial coefficient) confirms that the test meets the required criteria for the included questions and its overall consistency. Performing the Mann-Whitney rank test with a standard significance level α = .05, the statistically significant difference between males and females was found, on the other hand, no statistically significant difference between the students preparing for their prospective teacher careers and those with technical specializations in chemistry or physics was identified. This contradicts a common belief that students choosing teacher preparation programmes are generally worse in scientific performance and technical subjects. The results also show that about a quoter of the students come to university with a low level of their scientific reasoning skills which should be therefore supported and further developed in lecturing and teaching.
Keywords: *scientific reasoning, test evaluation, Lawson Classroom Test of Scientific Reasoning*

Introduction

In science, technology, engineering, and mathematics education (STEM) there has been increased emphasis not only on the learning of content knowledge but also on the development of skills connected with the skills important for practical science, including scientific reasoning. Generally, scientific literacy is currently considered one of the central goals for the development of 21st-century citizens and scientific reasoning ability is determined as an important factor for fostering student performance in science learning and has gained increasing attention from science educators and researchers. Moreover, scientific reasoning represents a hidden variable that can influence students' understanding of learning new concepts. Therefore, mapping the level of scientific reasoning skills within a class or a course may be useful to reveal students who have more difficulty in learning and may provide the information to develop an appropriate method which overcomes the pedagogical issues.

In the literature, there are many definitions of scientific reasoning. Following (Bao et al., 2009a) we accept the position that scientific reasoning represents the cognitive skills necessary to understand and evaluate scientific information, which often involves understanding and evaluating theoretical, statistical, and causal hypotheses.

https://doi.org/10.33225/BalticSTE/2021.74

Broadly defined, it includes the thinking and reasoning skills involved in the inquiry, experimentation, evidence evaluation, inference, and argumentation that support the formation and modification of concepts and theories about the natural and social world.

In 1978, Lawson designed an assessment instrument that measures students' level of scientific reasoning development (Lawson 1978). The paper and pencil style addressed the need for a reliable, convenient tool enabling to examine larger numbers of respondents that would be more practical for classroom use, compared to the Piagetian tasks. In 2000, building on previous work, Lawson developed an improved version of the assessment instrument, named Lawson's Classroom Test of Scientific Reasoning (LCTSR). It is a two-tier, multiple-choice test with 24 items (Lawson, 2000). A two-tier multiple-choice item pairs (questions 1–22) contain a question with some possible answer choices, followed by another question proving some possible reasons for the response to the previous question. According to (Zhou et al., 2021), a correct answer with incorrect reasoning indicates an intermediate level of reasoning development, whereas an incorrect answer with correct reasoning is likely a result of guessing. All the answer choices were designed based on previous studies on student misconceptions with free response tests, interviews, and relevant literature (for a more detailed recent review of the LCTSR development see e.g. (Zhou et al., 2021)). After more than 20 years we may conclude that the LCTSR is a practical tool assessing a unidimensional scale of scientific reasoning with good overall reliability, though inspections of individual question pairs revealed some validity concerns for several question pairs (Bao et al., 2018). Nevertheless, correlations were calculated between LCTSR scores and other measures of reasoning, and adequate values found. The Lawson test gained popularity among STEM educators and researchers, so far it has been given to several thousands of students and results were published in tens of papers, some of which are also referred to in this text. It is appropriate for a wide spectrum of contexts, namely intro colleges (which is also our case), high schools and middle schools.

In this research, the LCTSR, which assesses students' abilities in six dimensions including conservation of matter and volume, proportional reasoning, control of variables, probability reasoning, correlation reasoning, and hypothetical-deductive reasoning, was also used. All of the above-mentioned skills were identified as necessary for a successful STEM career.

The LCTSR scores at the beginning of the course may tell us a lot about our students' initial reasoning levels so that we get a better sense of which types of reasoning our students need more help with and can adjust appropriate teaching methods. According to the scores divided into 3 equal intervals, Lawson suggested classifying students into three formal reasoning categories: concrete operational (scoring up to 8 points, i.e., 33%), transitional (scoring between 9 and 16 points, i.e., 34% and 67%), and formal operational (scoring above 16 points, i.e., 67%). For the comparison of the score results, it is important to mention some other similar studies. For instance, (Bao et al., 2009a) report an average score of 75% based on the $N = 5760$ freshmen science and engineering students in four U.S. and three Chinese universities of medium ranking. On the contrary, (Sriyansyah & Saepuzaman, 2017) found among 29 first-year prospective physics teachers who attended introductory physics courses in 2015 at Indonesia University of Education no formal reasoner and 31% concrete reasoners.

A strong positive statistically significant correlation between students' pre-instruction scores for reasoning ability (measured by the LCTSR) and some tools

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measuring the conceptual knowledge in a particular field of physics has been reported in high school and university introductory courses, e.g., learning of forces and Newtonian laws (measured by the Force Concept Inventory) and basic concepts of electricity and magnetism (measured by Brief Electricity and Magnetism Assessment); see (Nieminen et al., 2012; Pyper, 2011; Sriyansyah & Saepuzaman, 2017). For the original Lawson 1978 test administered to secondary school students in Israel and the U.S.A. there was only a small correlation between achievement in science and maths and the Lawson test; and the Israeli population achieved significantly higher than the US students on the Piagetian skills measured by the test (Hofstein & Mandler, 1985). Also, (Maloney, 1981) reported statistically significant differences between the science-major and non-science major students (in the original Lawson 1978 test), with all six students with the lowest scores (concrete operational level) dropping the intro-physics course without completing exams. Similarly, (Moore, & Rubbo, 2012) have found that non-STEM (science, technology, engineering, and mathematics) majors taking either a conceptual physics or astronomy course at two regional comprehensive institutions scored significantly lower on the LCTSR in comparison to national average STEM majors (the majority of their non-STEM students can be classified as either concrete operational or transitional reasoners, whereas in their STEM population formal operational reasoners are far more prevalent). Scores on the LCTSR were then correlated with normalized learning gains on various concept inventories. The correlation was strongest for content that can be categorized as mostly theoretical, meaning a lack of directly observable exemplars, and weakest for content categorized as mostly descriptive, where directly observable exemplars are abundant. These results further demonstrate that differences in student populations are important when comparing normalized gains on concept inventories, and the achievement of significant gains in scientific reasoning requires a re-evaluation of the traditional approach to physics for non-STEM students.

Another question is, to which extent the scientific reasoning skills are related to students' performance and are supported within university introductory courses. For instance, (Bao et al., 2009a, Bao et al., 2009b) found that the rigorous learning of physics knowledge in middle and high schools makes a significant impact on the ability of students in China to solve physics problems, but this knowledge does not seem to have a direct effect on their general scientific reasoning ability. This suggests that current education and assessment in the STEM disciplines often emphasize factual recall over a deep understanding of scientific reasoning. Similarly, based on the results from two Chinese universities (Ding, 2013) shows that, regardless of their major, student reasoning skills measured by the LCTSR remained largely constant across the four years of higher education in accordance with (Pyper, 2011) and his data from several years and several different classes that have shown that Lawson test scores do not change much over the course of a single semester. Students of average and lower reasoning abilities struggle in solving problems that depend on conceptual understanding and may depend more readily on memorization of simple procedures to solve problems (Fabby & Koenig 2015). As pointed by (Piraksa, Srisawasdi & Koul, 2014), there is a critical area for improvement of students' scientific reasoning ability. In biology (Susilowati & Anam, 2017) successfully verified the 5E-learning model (Engagement, Exploration, Explanation, Elaboration, Evaluation) to be effective in scientific reasoning and problem-solving ability of students.

This all indicates, that LCTSR can provide valuable information and feedback for the course instruction, at least in some context. Therefore, it makes sense to ask, whether the results can be affected by some parameters, like gender or study programmes of the respondents.

Research Methodology

The LCTSR was tested with the students of the Faculty of Science, Palacký University Olomouc within the years 2018–2020 with the total number of *N* = 446 respondents (158 in 2018, 133 in 2019 and 155 in 2021) including chemistry-major and physics-major students (technical programmes, called non-teachers further in the text) and students in prospective science teachers' programmes (called teachers below). Let us remark that in the Czech Republic future teachers are typically specialized in two-subject combinations like e.g., maths-physics or chemistry-biology. The test was typically taken within introductory courses in the first week of the semester, thus the scores were not affected by any university-level instruction and rather correspond to the level of scientific reasoning at the end of their high schools. To motivate the students to think about questions seriously and not just randomly mark the answers, we gave them some extra points for the overall scores of the courses within which we have organized the testing. The organizing and scoring the test also followed the recommendations and instruction provided for LCTSR by PhysPort network support developed and maintained by the American Association of Physics Teachers (https://www.physport.org/assessments/).

After the scoring, the standard characteristics for test items and the whole test were determined as described below within the results sections. The standard characteristics of the test items and the test as a whole were determined according to (Ding et al., 2013; Eaton et al., 2019) where the corresponding formulas and recommended ranges are introduced. The item difficulty index *P* is a measure of the difficulty of a single test question. It is calculated by taking the ratio of the number *N*1 of correct responses on the question to the total number *N* of students who attempted the question (*P* = *N*1/*N*). The recommended values are in the interval <.3, .9>.

The item discrimination index *D* is a measure of the discriminatory power of each item in a test, it measures the extent to which a single test item distinguishes students with the better total scores well from those with lower ones. The possible range for the item discrimination index *D* is <–1, +1> with negative values for the questions answered better by the students with lower total test scores. There are more ways how to determine the groups with higher and lower scores based either on median or quartiles. In our case, following (Ding et al., 2013), we divided the whole sample of students according to quartiles and proceed with two different groups of equal size, a high group *H* and a low group *L* (using the top 25% as the high group and the bottom 25% as the low group). For a specific test item, one counts the number of correct responses in both *H* and *L* groups: namely, N_H and N_L. If the total number of students who take the test is *N*, then $D = (N_H - N_L)/(N/4)$. An item is typically considered to provide good discrimination if $D \geq .3$.

The point biserial coefficient (sometimes referred to as the reliability index for each item) is a measure of the consistency of a single test item with the whole test. It

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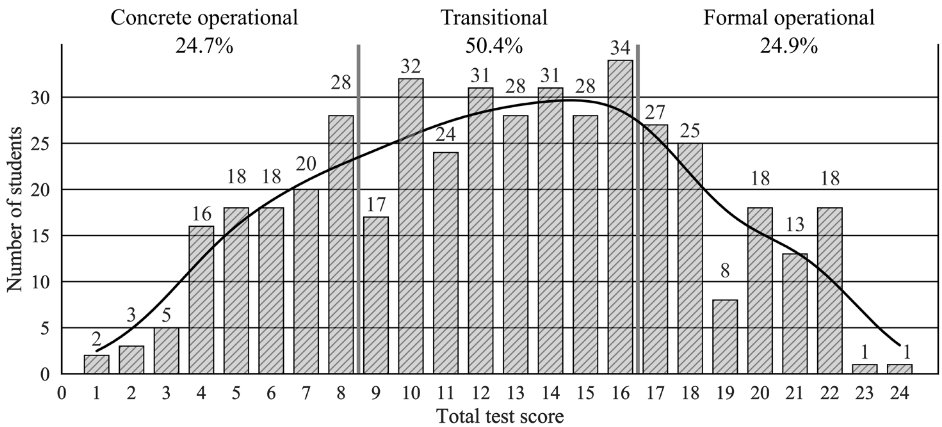
reflects the correlation between students' scores on an individual item and their scores on the entire test and is basically a form of the correlation coefficient. The point biserial coefficient has a possible range of <−1, +1>. Ideally, all items in a test should be highly correlated with the total score, but that is somewhat unrealistic for a test with a large number of items. The criterion widely adopted for measuring the "consistency" or "reliability" of a test item is rpbs ≥ .2 (Ding et al., 2013).

The Kuder-Richardson reliability index is a measure of the self-consistency of a whole test without administering one test twice or designing two tests, i.e., by using the information from one test administered just once. Using the formula KR-21 (Ding et al., 2013), possible values for the KR-21 reliability index fall into the range <0,1>. Different tests for various purposes have different criteria. A widely accepted criterion is that tests with a reliability index higher than .7 are reliable for group measurement and tests with a reliability index higher than 0.8 are reliable for individual measurement. Under most circumstances in physics education, evaluation instruments are designed to be used to measure a large group of students, so if a certain physics test has a reliability index greater than .7, one can safely claim it is a reliable test.

Figure 1

Histogram of Total Test Scores with a Density Estimate to Smooth the Distribution Shows that Nearly One Quarter of the Students Fall into the Lowest Piagetan Level of Concrete Operational Reasoning



Ferguson's delta is another whole-test statistic measuring the discriminatory power of an entire test by investigating how broadly the total scores of a sample distribute over the possible range. If a test is designed and employed to discriminate among students, one would like to see a broad distribution of total scores. The possible range of Ferguson's delta values is <0,1>. If a test has Ferguson's delta greater than .9, the test is considered to offer good discrimination.

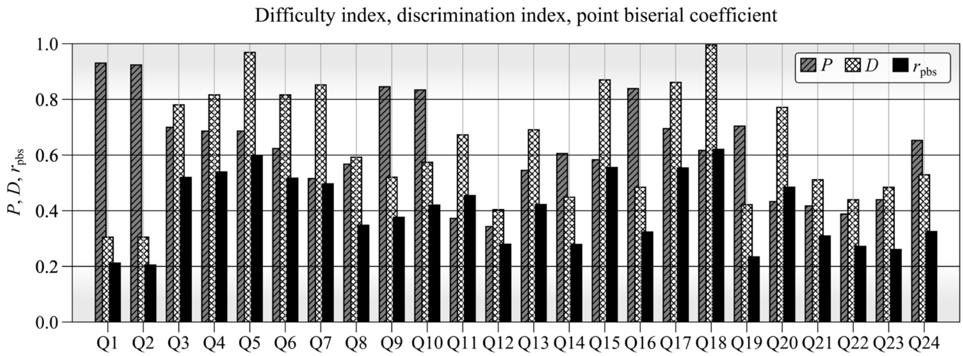
The scores in the six dimensions of scientific reasoning covered by the LCTSR were compared and a correlation matrix between them found to identify, which of them are most important for the overall test ranking. Based on the obtained results two hypotheses were tested – first, that the males over-score females and second, whether the students choosing the science teacher preparation study programmes reach a different level of scientific reasoning. Both hypotheses were checked by the Mann-Whitney U test with a significance level α = .05 and a two-sided *t*-test for identical means with the less strict assumption of different variances. The data and results from the years 2018 and 2019 were studied in a bachelor thesis, later the data from the autumn 2020 were included and previous conclusions confirmed. The statistical calculations were performed by the *Python* programming language using its open-source data analysis and manipulation library *pandas* and its module for statistical functions *scipy.stats*.

Research Results

The histogram of LCTSR scores for all N = 446 students is in Figure 1. The corresponding average is 12.7 (52.8% of the possible maximum), median 13 with a standard deviation of the distribution 5.13. It can be seen that nearly one quarter of the students entering our courses (24.7%) rank into the lowest category of concrete operational reasoning and approximately the same part (24.9%) into the highest category of formal operational, the rest (50.4%) belong to the transitional category. Only one student reached the full score of 24 points. In the context of the Czech Republic, among prospective physics teachers in the first year of their study at the Faculty of Mathematics and Physics, Charles University, Prague in 2011 there were only 9.3% concrete reasoners, and 59.3% students reached the highest level of formal operational reasoning. Therefore, our proportion of the students in the low concrete operational category is surprisingly high which may indicate that some students in this category could face problems in learning scientific concepts.

Figure 2

Item Characteristics for All 24 Questions in the LCTSR: Difficulty Index P, Discrimination Index D and Point Biserial Coefficient r_{pbs}



The density estimate to smooth our LCTSR scores distribution in Figure 1 shows the asymmetry in the direction of lower scores, which also confirms the negative skewness of the distribution – 0.0386. A negative kurtosis –0.817 means that the distribution is flatter than a normal distribution with the same mean and standard deviation.

The question-item measures are summarized in Figure 2. With the average difficulty index $\bar{P}$= .623 and the minimum value .343 for question 12, we can conclude

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that there are no extremely difficult questions with $P < .3$ in LCTSR. The maximum P values 0.930 and .924 belong to questions 1 and 2 respectively; those two easiest questions dealing with the conservation of mass are out of the suggested range, and we can mark them as too easy. Question 12 belongs to the pair of questions combining identification and control of variables and probabilistic thinking as a second question providing a reason for the answer to question 11.

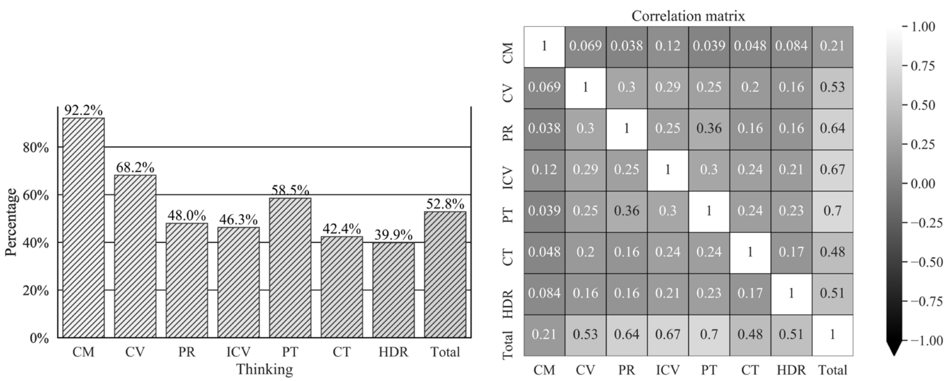
In our case, the average discrimination index $\overline{D} = .630$, with a minimum value .305 for questions 1 and 2 with the highest P values; the easiest questions naturally have the lowest discriminatory power (but still $D \geq .3$). The highest values of D correspond to questions 5 ($D = .969$) and 18 ($D = .996$) which represent proportional thinking and advanced probabilistic thinking, respectively. Similarly, our average point biserial coefficient $\overline{r_{pbs}} = .400$ is satisfactory, even the lowest values .212 and .205 for the easiest questions 1 and 2 respectively are above the limit .2.

The Kuder-Richardson reliability index value .847 obtained for LCTSR is again compatible with the criterium to be over .7 and shows the test can be considered as reliable. Obtained value for the Ferguson's delta .985 is also satisfactory (> .9).

In Figure 3 we can see the scores evaluated according to the categories of scientific reasoning and the correlation matrix among them and the total test scores. The most successful is the conservation of mass (92.2%), which corresponds to the easiest questions 1 and 2 as discussed above. Not surprisingly, the lowest scores correspond to hypothetico-deductive thinking and correlation thinking (39.9% and 42.4% respectively). It is in partial agreement with the Thailand study (Piraksa et al., 2014), in which the lowest scores correspond to hypothetical-deductive reasoning, control of variables and proportional thinking.

Figure 3

Scores in the components of scientific reasoning defined by Lawson (in percent to the maximum possible scores in those parts) and the corresponding correlation matrix (CM – Conservation of mass, CV – Conservation of volume, PR – Proportional reasoning, ICV – Identification and control of variables, PT – Probabilistic thinking, CT – Correlation thinking, HDR – Hypothetico-deductive reasoning, Total – Total test score)

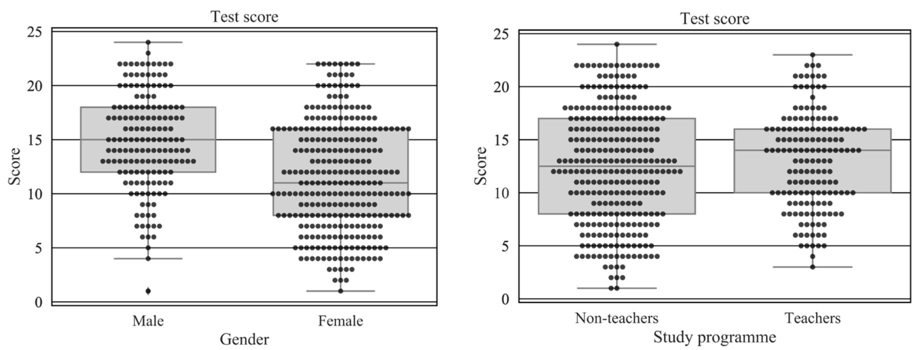


Also, (Moore & Rubbo, 2012) reported their non-STEM students to demonstrate significant difficulty with proportional and hypothetico-deductive reasoning. From our correlation matrix in Figure 3, we can see, that the mutual correlation among the scores in the categories are loose (all Spearman correlation coefficients below .5), a little bit stronger correlation can be found between the total test scores and identification and control of variables category, probabilistic and proportional thinking (Spearman correlation coefficients above .6). Recently, it has been shown by (Hejnová et al., 2018), that for the 14–15-year students the ability to use the existing knowledge strongly correlates with three dimensions of the scientific reasoning structure: proportional reasoning, control of variables and probability thinking, which demonstrates the highest correlation with the total test scores in our research.

Working with the test scores we noticed that there could be a significant difference in the performance of male and female students (see the box plot in Figure 4), which was also indicated in the data we privately obtained from the Faculty of Mathematics and Physics, Charles University, Prague. Among our respondents, there were 286 females with a mean score 11.5 (median 11, minimum 1, maximum 22) and 160 males with a mean score 14.9 (median 15, minimum 1, maximum 24). Mann-Whitney U test for the distributions and *t*-test of the scores for the mean score differences confirmed, that the difference is statistically significant (*p*-value .000). The results of other studies are not unequivocal in such a conclusion. For the original Lawson 1978 test administered to secondary school students in Israel and the U.S.A. was also found that, in general, males outperformed females (Hofstein & Mandler, 1985). On the other hand, the results of the Thailand LCTSR study (Piraksa et al., 2014) did not indicate that gender should significantly impact students' scientific reasoning ability. Similarly, the results of Indonesian research (Novia et al., 2018) showed that no statistical difference between male and female scientific reasoning mean scores were observed and that gender and age do not significantly impact students' scientific reasoning ability in the first year of university education. Thus, besides the fact the LCTSR was designed by a male, the gender difference in the mean scores may also have roots in the local cultural and historical backgrounds.

Figure 4

Box Plots Showing the Quartiles of the Datasets and the Whisker of the Dataset Extends for the Total Scores with Respect to Gender and the Kind of a Study Programme of the Respondents



Another important question we wanted to answer relates to a common belief and

https://doi.org/10.33225/BalticSTE/2021.74

opinion, that the carrier of prospective teachers is mostly chosen by students with worse high school results who give up or fail to proceed with more demanded study programs (e.g., law, economy, medicine, engineering, or technical science programs). Therefore, we checked whether there is a significant difference between "future teachers" and "non-teachers" in scientific reasoning skills measured by LCTSR. In our sample, the 156 prospective teachers reached a mean score 13.1 (median 14, minimum 3, maximum 23), 290 non-teachers mean score 12.5 (median 13, minimum 1, maximum 24). Both the Mann-Whitney U test (*p*-value .154) and the *t*-test for the different mean scores (*p*-value .234) confirmed, there is no statistically important difference in the distributions of the scores for those two groups. Thus, we can conclude, that at least within our Faculty of Science, the students of science education programmes should not be automatically taken as worse or with lower prerequisites to acquire, learn and understand scientific concepts and in solving problems. We certainly realize that might be rather a faculty-specific conclusion, and we cannot compare it with any similar study at this point.

Conclusions

It was demonstrated and verified the LCTSR is a relatively reliable tool fulfilling the demanded values for item characteristics like item difficulty index, discrimination index and point biserial coefficient (maybe except for the easiest questions 1 and 2, which may be considered as motivating). Also, both the Kuder-Richardson reliability index and Ferguson's delta measuring the test self-consistency and overall discrimination power meet usual criteria. We were also able to identify the identification and control of variables category, probabilistic thinking, and proportional reasoning as the key dimensions of the scientific reasoning correlating most with the total test scores. In our sample, there is a statistically significant gender bias of the score distributions, but students entering science education programmes achieved a comparable mean level of scientific reasoning as their colleagues enrolling in technical-scientific programmes.

The open problems for some further research should answer the relation between the LCTSR scores and possible learning gains within introductory courses, which is not generally straightforward. Also, it is not clear, to which extent scientific reasoning is developed within some types of courses.

On the other hand, training in scientific reasoning may also have a long-term impact on student academic achievement. With respect to relatively low mean scores for our sample, there is evidently demanded to develop and strengthen the scientific reasoning also within the introductory university courses, as most of our students belong to the transitional reasoners' category. Our results agree with (Bao, et al. 2009a), that students start to fully develop the basic reasoning abilities around their college years. The take-home message might be that the sorts of activities that require students to develop, explain and defend their reasoning help them to develop cognitively in ways that lectures or even peer interactions in a lecture-like environment cannot provide much effectively. We cannot assume that our incoming students are able to reason in the sophisticated ways which they need to really understand abstract and complex concepts like force and energy. If we do really care that our students get these concepts, we need to provide explicit opportunities to improve their reasoning. Hence, it is necessary to make reasoning explicit in the instruction. Although the reasoning abilities tested

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in the LCTSR may appear simple to expert scientists, these are crucial fundamental components for more sophisticated skills. However, to assess the reasoning abilities of senior college students and graduate students, we need to develop questions that involve more advanced reasoning components. This also implied that instructional pedagogy in science classrooms and university or college lecture rooms should be more emphasized on the way of teaching how to reason casually based on hypothesis generation, how to design well fair science experiments, and how to determine the correlation between target variables, to enhance the development of students' scientific reasoning ability.

Acknowledgement

The authors thank a lot to RNDr. Irena Dvořáková, Ph.D. (Department of Physics Education, Faculty of Mathematics and Physics, Charles University, Prague) for the introduction into the topic of the LCTSR, the Czech translation of the test and sharing her results collected within several years across the Czech Republic. The authors are also very grateful to the colleagues RNDr. Renata Holubová, CSc., RNDr. Marta Klečková, CSc., doc. RNDr. Roman Kubínek, CSc., Mgr. Zdeněk Pucholt, Mgr. Jan Říha, Ph.D., Mgr. David Smrčka, Ph.D., and Mgr. Vlastimil Vrba, Ph.D., for their kind help during the testing and data collection.

Declaration of Interest

Authors declare no competing interest.

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Received: *May 28, 2021* Accepted: *August 14, 2021*

Cite as: Hrouzková, T., & Richterek, L. (2021). Lawson classroom test of scientific reasoning at entrance university level. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 74-85). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.74

BIOLOGICAL SCIENCES PRE-SERVICE TEACHERS' EXPERIENCES OF COVID-19 AS AN ENABLER FOR THEIR SERVICE-LEARNING PROJECTS

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Abstract

The newspaper headlines in July 2020, reflected the context of COVID-19 and the challenges in the education sector in South Africa. Pre-service teachers completing a Biological Sciences for Educations Research and Service-Learning module conducted their Service-Learning in their home contexts, which under normal times, they would do so in the neighbouring university contexts. The research question: Why did the Biological Sciences pre-service teachers' experience COVID-19 as an enabler for their Service-Learning projects. An interpretive, qualitative case study was adopted to explore the pre-service teacher's experiences of their projects undertaken. The data gathering methods included document analysis (pre-service teacher's reflective diaries); observation of module reflective sessions and seminar presentations and visual methodology (pre-service teachers made videos). The data analysis using descriptive content analysis. The research rigour of credibility and dependability were worked with, and the research ethics were considered. The results indicated that during the learning about the project, the pre-service teachers had emotional experiences of fear, excitement and even confusion. During the planning for the project, they had concerns about Covid-19 restrictions and access to placement sites, what to do, who to work with and the nature of the projects planned. The action of the Service-Learning indicated the collaboration and teamwork, imagination and creativity, including the contextually relevant problem-solving actions that were undertaken. Pre-service teachers were in their own communities where they excelled and built relationships and valued their community members. Service-Learning should be completed in the pre-service teacher's home contexts for greater relevance, value and connectedness with their community.
Keywords: *biological sciences, case study, COVID-19 pandemic, pre-service-teacher education, service-learning*

Introduction

COVID-19 - Excess deaths point to hidden toll in South Africa; The primary goal of the South African COVID-19 response is to slow the spread of infections; South Africa has the world's fifth-worst Epidemic, with 471,123 cases; South Africa's R350 coronavirus grants will be made available to more people; South Africa crosses 400,000 mark; Schools closed amid virus. These newspaper headlines depict the context of South Africa during the pandemic. Reading these headlines and the articles linked to them is different to actually experiencing it directly, and being challenged by feelings of fear,

https://doi.org/10.33225/BalticSTE/2021.86

anxiety, hopelessness, including hope with growth for what can we do to influence the lives of communities in sustainable ways, and still expecting to be living a "normal" life as a teacher educator and working with pre-service teachers.

In the School of Education, Community Engagement embraces the University of KwaZulu-Natal Strategic Plan 2017 – 2021, Goal 3 (Strategic Plan, University of KwaZulu-Natal, 2017). This goal is concerned with Community Engagement which should be high impact societal and stakeholder community engagement that has meaningful interactions for mutual benefit. In the Southern African Higher Education sector, the strategic outcome of Community Engagement is in regard to social responsiveness and to contribute to the development of students, communities and Higher Education Institutions. This was in response to the call of the White Paper on the Transformation of Higher Education (Department of Education, 1997). The principals identified in this policy document are social responsibility, humaneness and social justice, and they are viewed as pivotal to engaging with communities.

In the context of South Africa and Higher Education, including Basic Education (schooling levels) the intensity of the pandemic was indicated by the newspaper headlines. Many issues experienced were linked to the extensive lockdown that was implemented by the government in March 2020. Since there was restricted movement of citizens and the closure of the universities and schools, students and learners experienced many challenges - access to the internet as online learning was implemented by the institutions that could afford it, lack of education resources and general attendance and access to learning, safety measures and the prevention of contracting the virus. Many learners (schooling level) and students (post schooling levels) were dealing with added trauma, including economic dislocation, hunger, and mental health challenges, all of which clearly affect learning, regardless of how it takes place.

Pre-service teachers completing a Biological Sciences for Educators Research and Service-Learning module were challenged with deciding what to do and how to complete their projects in the context of the pandemic. This was particularly important for the service with communities to be recognised and the pre-service teachers to achieve credits for the work that they had completed. Service-Learning may be defined as experiential learning that integrates practical experiences into the academic curriculum (Furco, 2001), with the life purpose aspect (Opazo, et al., 2018). As a teacher education institution integrating community engagement in a module gave credence to the Scholarship of Teaching and Learning (SoTL) (Shulman, 2000) focusing on the expectations, planning, and the actions for the completion of the Service-Learning. The Biological Sciences module was taught virtually to third-and fourth-year pre-service teachers in 2020 and focused on Service-Learning, both were engaged with. The 16-credit module comprises three 90-minute lectures per week for 5 weeks and one 90-minute lecture and Service-Learning placement site work for three to four hours per week, for seven weeks. During COVID-19, many issues regarding students working in communities were raised: a focus on service-Learning (more on the learning and less on the service) and minimal contact with communities (Morton & Rosenveld, 2021); the new digital face of Service-Learning where academic efforts were aligned with community priorities (Brooks, 2020). In the case of the pre-service teachers, due to COVID-19, they conducted their Service-Learning projects in their home communities, not in the areas around campus, in a mask to mask nature. So, a completely different contextual setting was to be engaged

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with the for project completion. So, a question raised is, Why did the pre-service teachers experience COVID-19 as an enabler/enhancer for how they planned and implemented their Service-Learning?

Research Methodology

General Background

An interpretive, qualitative, case study was undertaken to provide meaning and an in-depth understanding of the pre-service teachers' experiences of conducting their Service-Learning during COVID-19. They were expected to be of service in a mask to mask setting with the community and the learning was in discussions and reflections during the virtual sessions. The pre-service teachers provided service activities that did not entail teaching Life Sciences at a school, it could be working with any community organisation, which is referred to as a placement site. So, they had to find suitable placement sites in their home communities. These sites included farming areas, local primary schools, Early Childhood centres, Children's homes, police stations, old age homes, any organisation in their community that would accept them to be of service with the organisation. The nature of the service was decided in negotiation with the placement manager, taking the needs of the organisation and the competences of the pre-service teacher into account.

Sample and Procedures

The sampling method adopted was purposive, in that all the one hundred and seventy pre-service teachers, working in groups of two or three, with a total of 71 projects, were included. All these projects were sampled to provide a descriptive account of the nature of the service that was undertaken, in the engagement with communities. For an in-depth analysis only two projects that were based in rural, primary education sectors were purposively selected.

Since the module was presented in phases, the data gathering was also conducted within these: phase one was concerned with the expectations, informative and exploratory sessions at the beginning; phase two with the planning of the interventions, and phase three with the time spent working with the placement site managers. In each of the phases the pre-service teachers reflected on their thinking and feelings linked to the incidents that they experienced, document analysis of the pre-service teacher's reflective diaries. The module, reflective sessions were integrated in the three phases as well and it was during these times that the class shared their experiences – what they found out, their challenges, frustrations and successes, including their plans for action. The seminar presentation was in phase three where they shared the PowerPoint, video and photographs, including posters describing the service that they had completed in the placement site. The data analysis using descriptive content analysis and the SoTL framework indicated the data sets to be presented and discussed. The research rigour of credibility and dependability were worked with, and the research ethics were considered and acted on.

Research Results

Phase One

Phase one is concerned with the expectations, informative and exploratory sessions at the beginning of the module and the project initiation that the pre-service teachers experienced. The comments written and the statements made by the pre-service teachers were:

> "Many things were said by other students about what we could expect in the module, the module is stressful, and it can be confusing etc."
> "There is a lot of excitement and also new challenges in the module, as well."
> "Year 2020 became so stressful, and this was due to lockdown and what is expected of me"
> "I have experienced much anxiety and stress, and this is due to how I will be able to do this work, now with COVID-19"
> "Confusion as to what and how I will be of service with the communities".

These statements indicate the emotional experiences that the pre-service teachers underwent. This is not surprising as Service-Learning as a concept and the pedagogy used to facilitate their development of understanding of the knowledge and practices is different to that for facilitating a Life Sciences module. Community persons, past pre-service teachers who had completed the module and the challenges of being expected to write reflections, share them, and use them for constructing and revising the thinking and feelings that each person experiences, is far removed from the focus on just the cognitive development of each person. This year with the added pressure of being at home, in their own communities, many rural and very far from urban areas, the search for appropriate placement sites was increased.

Phase Two

Phase two is concerned with the pre-service teacher groups' planning for the interventions and the actual interventions planned. The comments made and statements written during the planning for the intervention included the following:

> "In planning for the groups, we struggled to find partners, especially ones that we would be able to work well together."
> "I wanted to work with a partner who was not living close to me, and this gave me many sleepless nights"
> "Finding placement sites was very difficult and added to that when one was found the issue of access due to COVID-19 was a real one"
> "We spent weeks looking for placement sites"
> "We needed enough data and money to be able to contact placement sites using our phones and then to work out the distances for travel to the site. We will require money for transport"
> "What – how will I and my group be able to work for 25 hours in the placement site. This is too much to ask"

These comments and statements were also shared during the class reflection sessions that we had once a week. The really purposeful and growing nature of these sessions was the collective suggestions and comments shared in a safe space about the emotional, physical and logistical experiences that the pre-service students shared. A problem for one group was a solution, motivator or an idea of the possibilities that the groups could work with. The sharing of frustrations and problems service as a release and comfort in knowing that each group is not the only one having a particular experience.

In focusing on the intervention, an analysis of these was completed, and the criteria used to categorise them were inductively decided on, it was the focus of each of the projects/programmes. The analysis of the intervention projects/programmes revealed the following:

Table 1
Categories and Number of Each of the Pre-service Teacher's Projects/Programmes

1 Food security	2 Special Needs	3 COVID -19 Related	4 Environmental	5 Health related
10	5	4	22	30

To provide further clarity on the categorisation of the pre-service teachers' projects/programmes the examples of the titles are presented below:

Category one has 10 projects, an example, Exploring and enhancing nutrition and food security among grade 3 learners at a primary school;
Category two has five projects, an example, Exploring and enhancing people living with cerebral palsy;
Category three has four projects, an example, Exploring and Enhancing the Cleaner's understandings of the effect of COVID-19,
Category four has 22 projects, an example, Exploring and enhancing land pollution awareness, and
Category five has 30 projects, an example, Exploring and enhancing healthfulness of Homeless people.

Phase Three

Phase three is concerned with an in-depth analysis of two of the projects. The visuals for each of these projects are also presented as the results:
Project one is concerned with category five – Health related as the basis of the programme was about the healthy state of the child and the healthy eating practices.

Figure 1
An Example of a Project in the Health Conditions Category

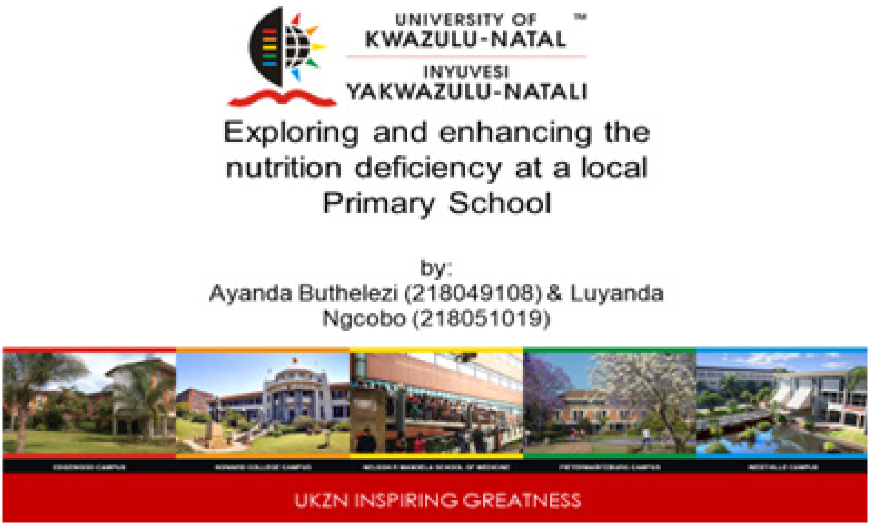
The group designed the intervention where the underlying principle is – Teach them until they understand the importance of hygiene and living a healthy lifestyle. The programme engaged learners in rhymes, music and movement in the indigenous language – isiZulu focusing on healthy foods and behaviours, demonstrating and acting on the washing of hands and the making and wearing of masks as a fashion and to be applauded. They also included the making and provision of healthy cooked meals (where they provided all the ingredients with their own money) to the children during the lunch break. The class group was also engaged in making and planting food crops in a school garden. Each child planted a plant in the garden and was responsible for taking care of it – watering it. The children were also educated about littering and keeping their environment clean, and they were engaged in a litter clean up around the school. The use of games was an important strategy for the learners to develop appropriate knowledge, skills and attitudes linked to healthy lifestyle.

In reflecting on their experiences, the pre-service teachers presented the following conclusion during their seminar presentation:

> Doing Service-Learning was amazing. This gave us an opportunity to engage with different people and to learn and explore how quickly the minds of young children are. From this experience we have learnt that it is within us to do good, we learnt that when we work together, we can achieve a lot of things. During our time at the site, one of our mentors told us that they never had time to teach the learners the importance of hygiene and living healthy. We really appreciated and enjoyed teaching young children about the importance of hygiene and living healthy.

Project two was concerned with food security, where the focus was on nutrient deficiency.

Figure 2
An Example of a Project in the Food Security Category



The pre-service teachers in this group discussed the nutrient deficiency with the teachers and principal at the school. They identified that the children's diet lacked proteins. The group then decided that in the time that they spend at the school, 25 hours, they will provide meals that are rich in proteins. They purchased food items to be cooked, lentils, beans that are also cooked with samp, an African traditional food consisting of dried corn kernels. Chicken was also added to some of the cooked meals. This group also taught the children to plant and played games focusing on food security.

They reflected on their experiences:

> Working with others, enabled us to develop our communication and listening skills. Working in groups on the sites made the experience more enjoyable. The motivation & encouragement we provided to each other was invaluable. We learnt a lot from Caitlin and Mrs Deca (the tutors) as well, sharing ideas and thoughts about their experiences in biology and seeing different perspectives and encouraging us to develop our own thinking skills and research skills.

Conclusions and Implications

The pre-service teacher's experiences were varied and expansive. The understanding and their attitude to the module in the initial part was acceptable, as they had no previous experiences of research, more especially Service-Learning and working with a community, as part of a module expectation. Furthermore, the work with communities is loaded with so many aspects linked to COVID-19 safety protocols, and the protection of self against infection, so health, emotional, physiological and psychological aspects need to be considered in the work with communities for the greater good. During the working with communities, this experience of learning in and with their community was certainly a different one for all concerned with the development of the mutually beneficial relationships. Mutually beneficial learning/engagement is significant in the emotional learning where statements made were, “working in the community is very amazing,” with the social learning evident from “experience was so amazing; I learnt the importance of spending time with other people,” and the respect “promises to be kept when working with a community” and attitudes of “amazing module with focus and honesty” and “work hard with honesty” were expressed. Some groups experienced much frustration when, “it did not end well” for them because they did not keep their promise of time and attendance at a placement site, and they were asked to leave.

Service-Learning during COVID-19 was a renewed way of working and even with the challenges experienced by the pre-service teachers of access, finding placement sites or even possible ideas for interventions taking the safety and security issues into account. Statements like, “through this module I have learnt a lot of things, I have grown as a life sciences teacher, and I would also advice those who think this module is difficult to drop the attitude.”

So, the enhancers are evident in the collaboration and teamwork that the pre-service students were engaged within and across their groups, and also with the placement of site persons. Working with a community for 25 hours, completing service that is mutually agreed upon, does entail the acceptance and role of the pre-service student in the place, to the achievement of the purposes identified. Since there are no pre-planned and clearly defined plans of actions that should be undertaken during the service periods, it is imperative that the pre-service teachers use their creativity and imagination to work with the opportunities and possibilities to design and implement a Service-Learning programme that is purposeful, practical, and sustainable. This entails the use of problem-solving strategies, which invariably are developed in that time with great support from the partners, lecturer, tutors, and groups for contextually relevant solutions to be implemented.

Acknowledgements

The author would like to thank Thembekile Zwane, Nondunduzo Ngubeni, Ayanda Buthelezi, and Luyanda Ngcobo.

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Received: *June 20, 2021* Accepted: *August 18, 2021*

Cite as: James, A. (2021). Biological sciences pre-service teachers' experiences of Covid-19 as an enabler for their service-learning projects. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 86-94). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.86

PRIMARY SCHOOL STUDENTS' NATURAL SCIENCE DIGITAL LITERACY COMPETENCE IN DIGITAL LEARNING ENVIRONMENTS

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Abstract

This study describes a research focused on primary teachers' evaluation of their students' digital literacy as a basic competence in the structure of natural science literacy of research and comprehension competence. With the term, primary teachers we mean teachers of first three grades of compulsory school. The comparison of basic computer skills between Generation Z and Generation Alpha revealed, contrary to expectations, a very small progress. The consequence of this circumstance are the problems associated with the implementation of natural science curricular goals in digital environments of remote teaching in school closure period. A questionnaire given to 176 primary teachers, revealed which digital learning environments could be chosen for science lessons and which curricular goals could/could not be achieved with this level of Generation Alpha students' digital literacy competence.
The results showed that the digital environment is more problematic and unfavorable for Generation Alpha in the field of natural science, as teachers showed a higher frequency of avoiding natural science goals than social science content.
Keywords: *distance learning environment, generation Alpha, natural science digital literacy competence, natural science education*

Introduction

Since the beginning of the third millennium, it had been clear that learning environments at all levels of the educational system would (and must) change, as a consequence of the digitalization process in professional and personal lives and as a consequence of the changes that this shift in communication from analogue to digital had made in the human brain. But no one had imagined that the shift from traditional to digital would happen in an instant, for all levels of education, for all students, and for all teachers – as it did with the closure due to COVID–19 lockdown all around the world.

Well, this change in learning environments took place in different contexts: There were countries (regions) that were technologically prepared. Their internet connections could handle multiple users per time, their students were equipped with computers and tablets, their teachers were digitally competent to teach in digital environments and, the students were already digitally competent to participate in the process of distance

https://doi.org/10.33225/BalticSTE/2021.105

learning in digital learning environments. It is assumed that all these factors occur simultaneously, and they usually do, but in the case of primary level of education, the last-mentioned factor – students' digital literacy – is a constant problem even in digitally advanced technological and digital learning environments.

In the context of natural science didactics in digital learning environments, the crucial question of primary level natural science education – besides the basic literacy problem – is students' natural science digital literacy competence. Previous research on students' digital competence for learning in digital environments points in two directions: Previous studies assumed that "digital natives" already enter school digital competent. Even more: Their digital competence is so far developed that they have nothing more to learn from their teachers, "digital immigrants" (Prensky, 2011; Spiro, 2004). Later studies (Cornu, 2011; Sadler, 2011; DeStefano&LeFevre, 2007; Kordigel Aberšek et. al., 2015), which measured the relationship between learning in digital environments and learning outcomes, noticed a remarkable difference between students with relatively high level of digital pre-knowledge and those with weak pre-knowledge. Meanwhile the generation changed. The primary grade students do not belong to the millennium generation, or, as they were called: Generation Y, anymore. They belong to Generation Alpha – they are children of Millennials and younger siblings of Generation Z. Generation Alpha is a generation born in (or after) 2010, the year the iPad was launched, and Instagram was created. Not only were their parents constant users of smart devices themselves (unlike the parents of Millennials, who struggled with new technologies), they used smart devices as pacifiers, entertainers, and educators, as screens were put in front of their children at the youngest possible age (McCrindle & Fell, 2020a). The consequence of a different digital environment in early childhood could lead to significantly higher level of (at least basic) digital competence at the age when children – Generation Alpha – enter school, which would enable them to successfully participate in digital learning environments (McCrindle & Fell, 2020b). This optimistic speculation usually overlooks what is expected of learning environments in the 21st century (DuMond & Instance, 2010). For natural science teaching/learning, the learning environment should provide the opportunity for a *social-constructivist* approach to learning, where learning/teaching takes place in the interaction between learners and their contextual situation, with learners actively constructing their knowledge and skills. Learning in such learning environments is/should be *self-regulated,* with active use of learning strategies, it should be situated in context and not abstracted from the environment, and it should be collaborative - not a solo activity (De Corte, 2010).

The Aim of the Study

The first aim of the research was to find out if and to what extent the digital literacy of Generation Alpha is advanced in comparison to the digital literacy of Generation Z. The second aim was to find out whether the digital literacy of primary students, age 6 – 8, reaches the level that can be used in the context of natural science digital competence for successful participation in social-constructivist based natural science class.

To find the answer to this central research question, the following research questions were formed:

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1. According to the teachers' assessment, how high is the level of primary students' basic computer literacy – the basic competence of natural science literacy of research and comprehension competence?
2. What digital learning environments did teachers use for science teaching during school closure in Slovenia?
3. How many natural science curricular goals were reached in these digital learning environments?
4. What natural science curricular goals were not reached in the digital learning environments and what are the reasons why teachers did not choose them during distance learning in the digital learning environments?

Research Methodology

The research background for establishing the difference/progress of digital literacy of Generation Alpha compared to the previous generation (Generation Z) was the study conducted in Slovenia in spring 2015, which examined compulsory and secondary school natural science teachers' assessment of their students' *new natural science literacies of online research and comprehension competence.*

Sample Selection

A sample were primary school teachers in Slovenia. Why in Slovenia? As mentioned above, four main factors influence students' performance in digital environments:

- technological factors (accessibility and quality) of internet connections,
- students' equipment with computers and tablets,
- teachers' digital competence to teach in digital environments and
- the fact that students were already digitally competent to participate in the process of distance learning in digital learning environments.

These four factors usually occur together, but not in Slovenia: In Slovenia both technology factors were solved very quickly, teachers were prepared to use digital learning environments in many projects.

Consequently, Slovenian primary school teachers are a reliable sample to find answers to the listed research questions. Our sample consisted of two sets of data. 135 teachers assessed their students' basic online skills, while 183 teachers responded to the questions about teaching in digital learning environments. The sample was random selected. Participants were not asked to give the sociodemographic data, because the research was not focused in interconnectedness between teachers' gender/the length of their teaching experience and the natural science teaching practice in distance teaching period, but in their evaluation of students' digital competence and in their teaching practice, connected with natural science curricular goals.

Ethical Procedures

Participants' approval was obtained in research in line with the voluntary principle. All participants were informed about the purpose of the research. At all stages, the identities of the participants were kept, and the codes, given to the participants were used when quoting raw data texts.

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Instrument and Procedures

The first set of data was collected using a 5-point Likert scale questionnaire, consisted of 21 items. The instrument was adapted from the TICA checklist, developed as part of the Teaching Internet Comprehension Skills to Adolescents project, which focused on learning skills, essential for online reading comprehension (Leu et al., 2008). The original TICA online reading comprehension checklist included items from five areas necessary for online reading comprehension: understanding and developing questions, locating information, critically evaluating information, synthesizing the information, and communicating the information. The adaptation used for our study focused on computer basics (Appendix A in the original survey), and the number of items was reduced – from 29 to 21 in the computer basics checklist.

The second set of data was collected through the online questionnaire *Learning environment for the first three grades in the time of remote teaching,* which contained 52 questions regarding teachers' experiences after COVID–19 school closure (11 weeks in Slovenia).

Data Analysis

Quantitative data from primary school teachers were collected. After verifying that the data were free of errors, quantitative analyzes were conducted and analyzed according to the following stages, or by encoding, defining, and organizing the data and interpreting the results. For the statistical processing of the data an IBM SPSS program was used. For basic statistical interpretation of the results, number, structural percentage, mean and standard deviation of the data were used.

Research Results

The findings ascertained from this research are presented in two parts. The first part presents data of primary school teachers' judgement of their students' computer basic skills, their web searching basics and general navigation basics, skills that are the basement of digital competence, needed for participation in digital learning environments. The second part presents data about natural science education in the period of school lock down, implementation of natural science curricular goals and reasons, why certain natural science curricular goals were not chosen for didactic units in digital learning environments.

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Table 1
Primary School Teachers' Ratings of Their Students' Basic Online Skills

Basic online skills	Generation Z (2015)		Generation Alpha (2021)	
	M	*SD*	*M*	*SD*
1. Computer Basics				
Turn a computer on/off	4.41	1.07	4..6	0.89
Use the mouse/track pad	4.35	0.91	4.29	0.83
Follow classroom and school rules for computer use	3.47	1.14	3.70	0.91
Open programs and files using icons and/or the Start Menu (PC)	2.88	0.82	3.32	0.91
Create/open a new folder/file	1.94	0.95	2.05	0.89
Launch a word processor	2.06	0.84	2.16	1.00
Open a word processing file	1.88	0.97	2,15	1.02
Type a short entry in a word processing file	2.00	0.83	1.89	0.95
Copy text	1.76	1.23	1.97	0.95
Cut text	2.24	1.04	2.35	1.11
Past text	1.82	1.01	1.95	0.90
Name a word processing file and save it	1.71	0.97	1.90	0.99
Open a new window	2.24	1,13	2.36	1.11
Open a new tab	1.65	0.87	1.59	0.79
2. Web Searching Basic				
Locate and open a search engine	2.00	0,85	3.35	1.27
Type key words in the correct location of a search engine	2.71	0.91	3.06	1.24
Use the refresh button	1.94	1.14	2.25	1.10
Use the “BACK” and “FORWARD” buttons	2.65	0.82	2.84	1.12
3. General Navigation Basic				
Maximize/minimize windows	2.18	0.7	2.48	1.08
Open and quit applications	2.76	0.81	3.26	1.18
Toggle between windows	2.00	0.89	2.58	1.03

Comparison of the results shows that basic computer competence in Generation Alpha developed less than expected in the context of the digital stimulating environment from the earliest age. Over the last 6 years, the results have changed only slightly. Generation Alpha enters the school hardly computer literate. Almost all of them can turn the computer on and off and use the mouse/trackpad, which they had probably learned while using digital devices for play/fun and perhaps socializing, but a large majority of them do not have other 21 basic computer skills that they would have needed to participate in the educational process in digital learning environments.

https://doi.org/10.33225/BalticSTE/2021.105

Table 2
Learning Environments for Teaching Science in the Distance-Learning Period

		Videoconference	Email	Online learning environment	Social networks	Phone calls	Other*	Other
1	*f*	2	32	66	149	79	104	51
	f %	1.14	18.18	37.50	84.66	44.89	59.08	80.95
2	*f*	3	14	4	6	23	13	1
	f %	1.70	7.95	2.27	3.41	13.07	7.39	1.59
3	*f*	0	7	1	1	22	17	1
	f %	0.00	3.98	0.57	0.57	12.50	9.66	1.59
4	*f*	13	35	6	9	26	24	3
	f %	7.39	19.88	3.41	5.11	14.77	13.64	4.76
5	*f*	61	30	6	5	17	11	3
	f %	34.66	17.05	3.41	2.84	9.66	6.25	4.76
6	*f*	97	58	93	6	9	7	4
	f %	55.11	32.96	52.84	3.41	5.11	3.98	6.35
Total	*f*	176	176	176	176	176	176	176
	f %	100.00	100.00	100.00	100,00	100.00	100.00	100.00
SD		5.4	4.1	3.9	1.5	2.5	2.1	1.7
Mean		0.9	1.9	2.4	1.3	1.6	1.6	1.6

Note: Other* – Mentimeter, BookCreator, Padlet, Plickers, Quizlet, Kahoot, Thinglink ...; 1 – Never, 2 – Once a month, 3 – Once every two weeks; 4 – Once a week, 5 – Up to 3 times a week, 6 – Daily

Students' limited basic computer skills did not prevent teachers from using digital learning environments under distance learning conditions during the COVID–19 closure. The results in Table 2 show that more than half of them used video conferencing (Zoom, Teams, Meet, etc.) almost daily, a similar percentage used Moodle, Mahara, 0386, Seesaw, Google classroom, classroom e-assistant Xooltime (online learning environment), only one third used email connection. These results can be explained in the context of parents' complaints about being overloaded with teachers' expectations for participation in primary students' homeschooling during the COVID–19 school closure.

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Table 3
Science Curricular Goals Reached during the Remote Teaching Period

	f	*f* %
One fifth of curricular goals and less	2	1.30
A quarter of curricular goals	4	2.60
One third of the curricular goals	13	8.44
Half of the curricular goals	21	13.64
Two-thirds of the curricular goals	19	12.34
Three-quarters of the curricular goals	41	26.62
Almost all or all curricular goals	54	35.06
Total	154	100.00

Table 3 shows that only a little over one-third of the teachers managed to reach all of the science curricular goals according to the annual plan, they prepared before the October closure. A quarter (25, 98 %) of the teachers admitted that they were only able to achieve half or even less of the science curricular goals. These results urge us to seek the answer to the question presented in Table 4: What science curricular goals teachers decided to teach/not to teach in digital learning environments.

Table 4
Curricular Goals, for which Primary Teachers Decided that They Are/Are Not Achievable in Digital Learning Environments

	Achievable goals						**Unachievable goals**									
	Goal 1		**Goal 2**		**Goal 3**		**Goal 1**		**Goal 2**		**Goal 3**		**Goal 4**		**Goal 5**	
	f	*f* %	*f*	*f* %	*f*	*f* %	*f*	*f* %	*f*	*f* %	*f*	*f* %	*f*	*f* %	*f*	*f* %
Social sciences	14	40.00	13	61.90	8	42.11	6	37.50	5	41.67	0	0.00	1	50.00	0	0.00
Biology	10	28.57	4	19.05	5	26.32	4	25.00	4	33.33	1	16.67	1	50.00	2	100.0
Physics	11	31.43	4	19.05	6	31.57	6	37.50	3	25.00	5	83.33	0	0.00	0	0.00
Total	35	100.0	21	100.0	19	100.0	16	100.0	12	100.0	6	100.0	2	100.0	2	100.0

The results in Table 4 show that most of the achievable goals are from the field of social sciences, while several goals for which primary school teachers decided they are not achievable in digital learning environments derives from the field of physics and biology. These results initiated the next research question: which were the reasons for teachers, not to choose the curricular goals from the fields of natural sciences to engage with in the digital environment.

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Table 5
Reasons for Not Selecting Natural Science Curricular Goals in the Digital Learning Environment

	1		2		3		4		5		6		7		Total	
	f	*f%*	*f*	*f%*	*f*	*f%*	*f*	*f%*	*f*	*f%*	*f*	*f%*	*f*	*f%*	*f*	*f%*
Goal 1	2	4.35	1	2.17	9	19.57	4	8.70	20	43.47	7	15.22	3	6.52	46	100.00
Goal 2	2	9.09	1	4.55	2	9.09	2	9.09	10	45.45	3	13.64	2	9.09	22	100.00
Goal 3	1	9.09	0	0.00	1	9.09	0	0.00	5	45.46	3	27.27	1	9.09	11	100.00
Goal 4	1	25.00	0	0.00	1	25.00	1	0.00	2	50.00	0	0.00	0	0.00	4	100.00
Goal 5	0	0.00	0	0.00	0	0.00	1	33.33	2	66.67	0	0.00	0	0.00	3	100.00

Note: 1 – Students were not present, 2 – The curriculum is overloaded, 3 – The goal is too demanding, 4 – No digital learning resources available, 5 – Distance learning requires a different didactic approach, 6 – Limited students' digital competence, **7** – My limited digital competences.

In the field of natural sciences (goals 1, 2 and 3), teachers mostly decided not to teach in digital learning environments because *distance learning requires a different didactic approach*, followed by *the goal is too demanding* and *limited student' digital competence* (Table 5).

Discussion

The results from our research are consistent with previous results, gained in a meta-analysis by Delgado and his team (Delgado et al., 2018). As we, they expected newer generations to achieve better learning outcomes in digital environments than older ones. In their meta-analysis, which included studies from 2000 to 2017 with a sample of 171.055 participants, they examined, whether the publication date of the study »reveals a decreasing advantage of paper in recent years due to greater exposure to technology than in earlier years« (p.7). Contrary to expectations, the meta-analysis showed that earlier (and longer) exposure to digital media has a diametric effect (Duncan et al., 2015; Pfost et al., 2013): Not only were there no differences between age groups across the years, but the results also obtained later show poorer reading and learning outcomes in digital environments. This is consistent with our findings showing that, contrary to expectations, primary students – Generation Alpha – do not have sufficiently developed digital competence to participate effectively in digital learning environments – which presents a major challenge for primary teachers, as our research has shown, how to perform the natural science class.

Conclusions

In conclusion, a call is needed for researchers, policy makers, and educational experts to develop methods that support effective digitally based natural science teaching and learning in digital learning environments for very young Generation Alpha students,

https://doi.org/10.33225/BalticSTE/2021.105

who have very limited digital literacy skills in addition to their still emerging general literacy skills.

Declaration of Interest

Authors declare no competing interest.

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Received: *June 10, 2021* Accepted: *August 15, 2021*

Cite as: Legvart, P., Kordigel Aberšek, M., & Kerneža, M. (2021). Primary school students' natural science digital literacy competence in digital learning environments. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 105-114). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.105

EXPLORING THE EFFECTIVENESS AND IMPACTS OF DIFFERENT TYPES OF MEDIA IN SCIENCE LEARNING

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Abstract

The spread of COVID-19 has caused a high demand for online learning or self-learning at home. We focus on evaluating which media is most suitable for self-learning for the third graders. For effective assessment of children's learning, the study adopted AEIOU: Awareness; Enjoyment; Interest; Opinion formation; and Understanding as the evaluation framework.

In this research, three types of media were implemented: animation, educational video, and science comics. Total 145 third graders were divided into three groups: animation group, educational video group, and science comics group, to learn the concept of heat transfer through one kind of media respectively. The results revealed that students had positive feedback on the three dimensions of Awareness, Enjoyment, and Interest. And all three media improved students' understanding of heat transfer without a difference. While in the dimension of Opinion formation, the students had less life experience and pre-knowledge, their performances were relatively low.

In summary, the three types of media showed the effectiveness of self-learning for the third graders. Especially the animations proved to be the most suitable for the third-grade children to conduct self-learning.

Keywords: *science communication, AEIOU, heat transfer, Media*

Introduction

Background and Research Purposes

Since the spread of COVID-19 in 2019, countries have begun to adopt different lockdown measures as the epidemic has become more and more severe. This includes decisions that affect education such as closing schools, suspension of schools, suspension of classes, and so on. António Guterres (2020), the ninth secretary-general of the United Nations, also pointed out: As of mid-July 2020, more than 1 billion students have been affected by the suspension, which results in at least 40 million children not able to attend preschool. Such learning crisis may cause "generational catastrophe". Therefore, the needs of using media for online self-learning and self-learning at home have arisen. Regarding online or home-based self-learning, it is necessary to use media to deliver the information. This study aimed to investigate which type of media can convey the concept of heat transfer to elementary school students most efficiently? Which types of media are elementary school students more interested in? Previous studies reported that the use of media should also consider how to communicate efficiently. The function

https://doi.org/10.33225/BalticSTE/2021.115

of media is not only to deliver the scientific information, but also to shape scientific information (Dimopoulos & Koulaidis, 2002). If media can correctly disseminate scientific information, it can improve the public's judgments and enable them to illustrate ideas clearly when participating in the discussion of scientific issues. In addition, it encourages the public to actively participate in the formulation of science and technology policies (Chin & Chen, 2007; Norris & Phillips, 2003). In order to correctly evaluate the effectiveness and impacts of different types of media used, it is necessary to first explore the definition of science communication, to understand which aspects can be used to evaluate the purpose of this research and develop evaluation instruments.

Science Communication

As the well-known Bodmer Report (The Royal Society, 1985) highlighted the issue of the insufficient scientific knowledge in public, the public began to realize that it might affect the development of science, and this resulted in several waves of research and discussion on science communication. Since the 1990s, the main model for research and practice of science communication has changed from the deficit models to the engagement models (Wynne, 1992; Sturgis & Allum, 2004). The deficit models emphasized the one-way knowledge transmission from teachers to students, stating that if the public does not have sufficient scientific knowledge, it will indirectly affect the support for science. On the other hand, the engagement models advocated that the decision-making of public issues be participated by the public in two-way communication, as opposed to the past decision-making style dominated by the experts (Hung, 2017). From this point of view, related scholars in science communication believe that the public must be able to make more meaningful decisions when facing science-related issues in society. Therefore, the public should have more and more extensive conversations with teachers or scientists, not just receiving knowledge (Baram-Tsabari & Osborne, 2015). To be able to effectively evaluate the effectiveness of a two-way communication, the definition of science communication must first be clearly stated.

Burns et al. (2003) stated that the boundary between the definition of science communication and the terms used in the field of scientific literacy was blurred. In view of this, Burns et al. (2003) pointed out the ambiguity between the definition of science communication and the terms used in the field of scientific literacy. In view of that, Burns et al. (2003) compiled a list of elements used in a two-way communication model (e.g., engagement model), for example: public awareness of science (PAS), public understanding of science (PUS), scientific culture (SC), or scientific literacy (SL), etc., and further listed the definitions that are suitable for the science communication. When there is a definition of the science communication, it cannot only promote science, but also serve as a basis for evaluating the effectiveness of science communication.

Theoretical Framework

Burns et al. (2003) defined science communication as “the use of appropriate skills, media, activities, and dialogue to produce one or more personal responses to science” (p.191). These responses are classified into five categories (the AEIOU vowel analogy): Awareness, Enjoyment, Interest, Opinion formation, and Understanding. AEIOU can be

https://doi.org/10.33225/BalticSTE/2021.115

used as the common goal of science communication and science education. It also provides a framework for this research to evaluate the effectiveness of science communication, which can be used to analyse the public's response to science communication activities or experiences. The details of each category are described below.

(1) Awareness: For science, it provides a basis for knowledge, broadens thinking, and creates opportunities for individuals to participate in scientific activities (Burns et al., 2003). Awareness of science is an important consideration for the public to participate in science communication activities. This study defines awareness as being aware of the importance of science and technology and being able to understand nature of science.

(2) Enjoyment: Enjoyment may evoke positive feelings and attitudes of participants, so that participants are more likely to produce subsequent and in-depth scientific activities (Stocklmayer & Gilbert, 2002). This research regards enjoyment as the pleasant life experience brought by today's technology.

(3) Interest□Krapp et al. (1992) stated that innovation and appropriate scientific communication activities can inspire the personal interest of participants. This activity can also stimulate participants' interest in the situation and further enhance participants' recall and understanding of the event. This research regards interest as the tendency and intention to participate in scientific issues, events, or activities.

(4) Opinion formation: Opinions are closely related to knowledge, beliefs, and emotional responses, and are deeply influenced by them (Crawley & Koballa, 1994). Therefore, this part of the research is not easy to implement. The most effective science communication one can produce is for participants to reflect on, form, reform or confirm their attitudes towards science and society (Burns et al., 2003). In this research, the formation of opinions is defined as opinions or viewpoints formed in the reflection of the public to support their arguments on certain scientific issues.

(5) Understanding: Understanding of science includes comprehension of scientific content, processes, and social factors (Burns et al. 2003). It emphasizes the application and meaning of science. This research defines this understanding as the understanding of the acquired scientific knowledge.

Science communication is committed to enhancing the awareness of science, scientific understanding, scientific literacy, and scientific culture through the AEIOU responses established by participants (Burns et al., 2003).

Research Methodology

Background

This research adopted a quasi-experimental design, the purpose was to explore the impacts and effectiveness of using different media to illustrate the concept of heat transfer among the third-grade students in elementary school. The participants of this study were six classes of the third-grade students, later divided into three groups: two classes were animation group, two classes were educational video group, and two classes were science comic group. Each group was used for three standard class periods which were 120 minutes in total. Based on AEIOU as the evaluation framework, each group conducted the pre-test of Understanding test, and then watched the media of each group. The media materials included animations, educational videos, and science comics that were all about the concept of heat transfer. Afterward, the groups performed the post-test of Understanding test; subsequently, each group had to watch or read the other media. After watching or reading all three media, students would take the AEIO questionnaire. Finally, statistical analysis on the quantitative results of the AEIU was used, for the open-ended responses from O need to be coded before analysis.

Participants

A total of six classes of third-grade students in an elementary school in Taiwan were chosen as participants (*N* = 145) with an average age of 9 years old. This research used a cluster sampling. The two classes were treated as one group, and six classes were divided into three groups: animation group, educational video group, and science comic group. There were 49 people in the animation group, 48 people in the educational video group, and 48 people in the science comic group. Before the experiment teaching, all the participants had not been exposed to the related concepts of heat transfer. Because of the small scale of samples, the inference of the research results was limited, and it was only suitable for the students who infer to the sample of this study and situations similar to this research. To infer this research results to other groups or educational fields, the applicability needs to be evaluated carefully.

Introduction of media used in the experiment

This study used three different media; the description of these media is as follows:

(1) Animation: In 1980, the International Association of Film Animation (ASIFA) defined animation as " in addition to real actions or methods, various techniques are used to artificially create dynamic images " (Liu, 2009). The animation materials used in this study were from Junyi Academy website, which is a non-profit educational organization in Taiwan that uses an online learning model. This website focuses on providing equal and high-quality educational resources for every child, and through technological instruments to help teachers and parents to teach in accordance with learners' aptitude. Thus, let children develop the habit of self-learning and become life-long learners (Junyi, 2021). Since the animation playback will be paused during the question time, it will continue to play only after the question is answered, which increases the opportunities for online self-learning and interaction.

(2) Educational Video: The educational video provides both sound and image elements at the same time. Learners can use the continuous sound and images to more easily understand the details that originally required a lot of text description. The educational video does not have an interactive design, and the learners receive the video information unidirectionally, and the learning process is relatively boring (Huang, 2014). The educational videos used in this research are specially filmed with textbook content. The advantage of the educational videos is a direct presentation of a realistic situation. With narration, text, and simple symbols (such as arrows), the teaching content can be presented simply and clearly, and the learners will be more deeply impressed.

https://doi.org/10.33225/BalticSTE/2021.115

(3) Science Comic: Xiao (2002) has made a simple analysis of the composition of comics, dividing the elements of comics into four parts: "image", "text", "frame", and "story". The Science Comics used in this research refers to comics that contain scientific elements, and " The King of Science Experiments (10)-The Flow of Heat" was used as the reading material for the science comics group.

The King of Science Experiments is published by San Cai Publishing House. It was originally a South Korean comic and has now been translated into Chinese. This set of books takes "competition for experimentation" as the main plot, and the protagonist participates in the experiment competition and brings out learning knowledge. In addition to comics throughout the book, there are also collocation articles to tell scientific knowledge. However, the scientific knowledge content of this book is relatively less. The whole book contains 200 pages of text, 183 pages of comics, 17 pages of scientific articles, and 15 pages of knowledge related to heat transfer.

Table 1
The Media Used in the Experiment

Media type	Source	Heat transfer conception	Time
Animation	Junyi academy website	heat conduction heat convection heat radiation	10 minutes 58 seconds
Educational Video	Online resources produced by textbook publishers	heat conduction heat convection heat radiation	10 minutes 36 seconds
Science Comics	The King of Science Experiments (10)	heat conduction heat convection (Note: Another heat radiation article is attached)	30 minutes

Research Procedure

After dividing the students into three groups, all three groups first accepted the pre-test of the Understanding test. After that, the Animation group first accepted the animation viewing, the Educational Video group first watched the educational video, and the Science Comics group first read The King of Science Experiments (10). After the first step was finished, all students would conduct the post-test of the Understanding test. After the post-test, each group needed to watch or read the other two media, for example: The Animation group needed to watch the educational video and read science comics. After watching or reading all the media, the AEIO questionnaire would be implemented.

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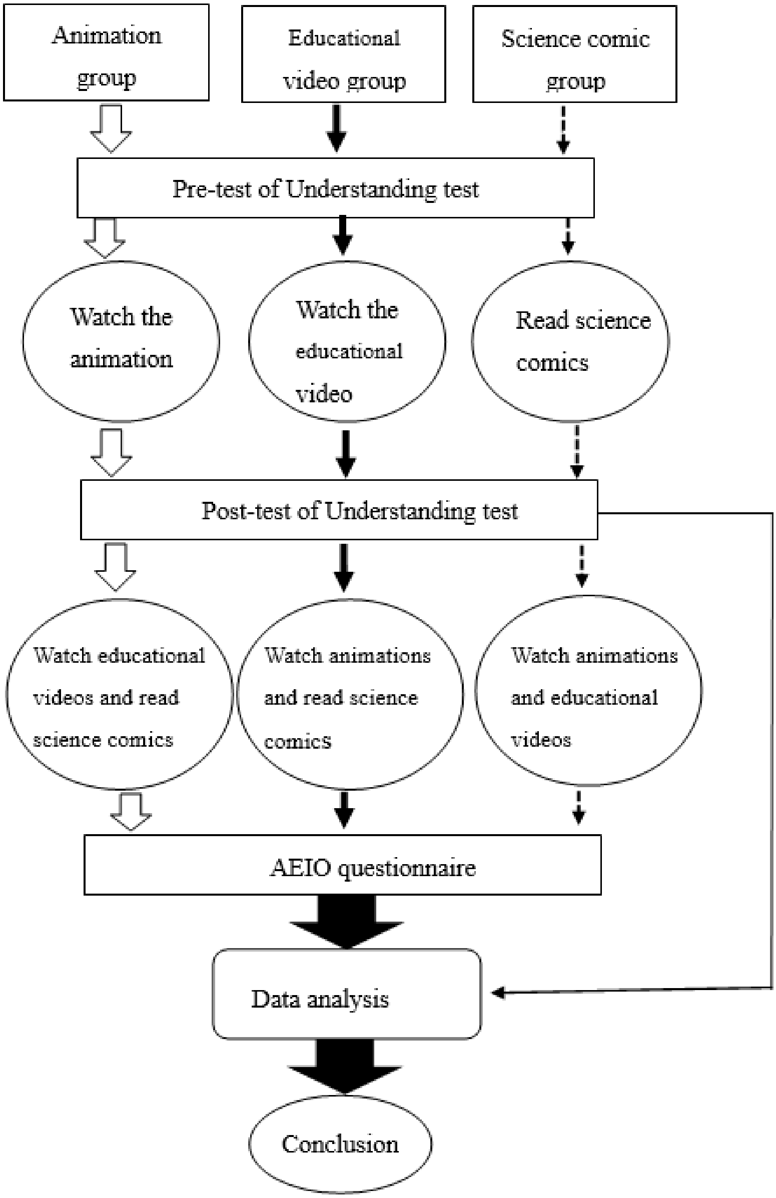
Figure 1
The Summary of Research Procedure



Assessment instruments

(1) The AEIO questionnaire was adapted from a Scale for Science Edu-Communication (Wu et al., 2019). The scale had undergone statistical tests and had proven to be a valid and reliable instrument to measure the effectiveness of science communication. The validity of AEIO questionnaire was established by expert judgment, and we used SPSS 17 to run test-

retest analysis of AEI dimensions. The Pearson's correlation coefficient was 0.916 > 0.7, so the AEI questionnaire had a high degree of reliability. The data of Opinion formation was qualitative, so the reliability test was not performed.

(2) This study designed 31 items of heat transfer at first, and then 49 students in the third grade were chosen to undertake the preliminary examination. According to the results of preliminary examination, some items were rejected due to their poor discrimination index. Finally, there were 16 items in the Understanding test.

Table 2
Question Types of AEIOU and Number of Items

AEIOU Dimensions	Number of Items	Question Type
Awareness	6	*5-point Likert scale*
Enjoyment	6	
Interest	6	
Opinion formation	1	Open-Ended
Understanding	16	Yes/No Questions and Multiple-Choice Questions

Research Results

AEI Questionnaire

A 5-point Likert scale was used to measure AEI dimensions. The scoring of AEI was from 1 point (completely disagree) to 5 point (completely agree) with a higher total score designating higher levels of AEI. Based on the above calculation of the average score and the analysis result, it was found that the average score of the AEI dimensions was above 4. This data showed that no matter what kind of media teaching, students had a positive attitude towards AEI dimensions. Among them, Awareness had the highest score of 4.241. This study also analysed the impact of three media on AEI dimensions. Among the three media, the animation group got the highest average score in the two dimensions of Awareness and Enjoyment, and the science comic group had the highest average score in the Interest dimension.

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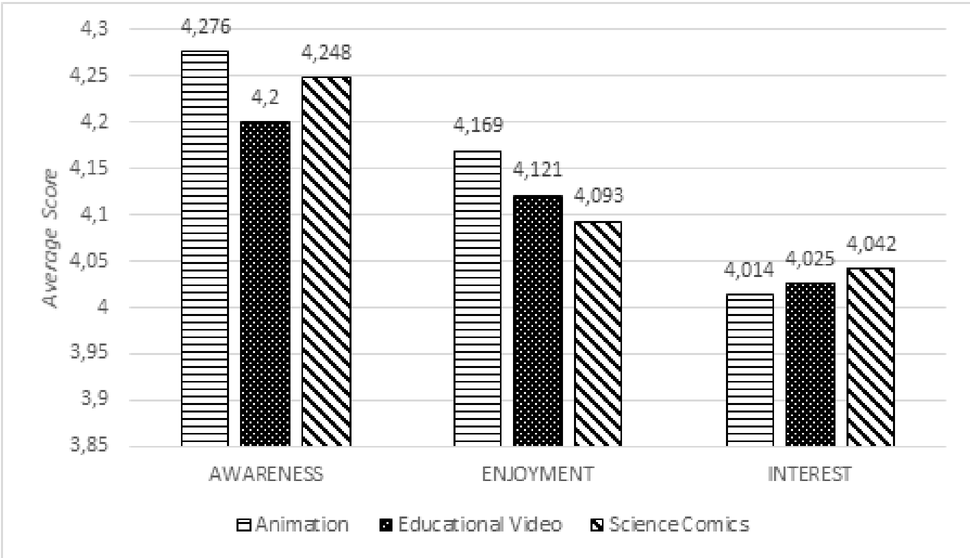
Figure 2
An Average Score of Different Media on the AEI Questionnaire



Open-Ended Questions of Opinion Formation

The question of Opinion formation was that" if you have a house, what can you do to make the people feel cooler in the house? Please try to explain from the installation of air-conditioning, the treatment of the wall, the position of the window, etc." After integrating the answers, it was found that because the third-grade students had a limited vocabulary and insufficient discussion skills, the proportion of answers was not high and only short words were answered. The answers of Opinion formation were coded and analysed, they were divided into heat conduction group, heat convection group, heat radiation group and error groups.

Table 3
Analysis of the Answers of Opinion Formation

Group	Examples of answers	Number of Students	Ratio
Heat Conduction	N/A	0	0%
Heat Convection	The air-conditioning is installed on the ceiling, above the room, and windows are installed on the left and right sides of the house, etc.	49	29.7%
Heat Radiation	Painted white walls	33	20%
Error	Did not write, air-conditioning installed next to the TV, windows installed next to the door, etc.	83	50.3%

Note: The question can have more than one answer, so the calculation of the ratio is the number of students with a certain answer / total number of answers

From the results, we know that students were more familiar with the concept of heat convection and have a higher rate of correct answers. However, the students may be influenced by the question, so they did not answer in the aspect of heat conduction at all. Basically, the third-grade students may be limited by insufficient life experience, insufficient language skills, insufficient scientific knowledge, and other factors, so their performance in Opinion formation was bad.

Understanding Test

In order to compare the post-test scores influenced by the three groups of media, we used the analysis of One-Way ANOVA (Lin, 2014) to determine whether there were any statistically significant differences between the means of three groups. After the analysis of One-Way ANOVA (by SPSS 17), the F value was 0.208, and the significance value was 0.812(p = .812) which was above 0.05. Therefore, there was no statistically significant difference in the three groups of media. Thus, the three groups of media had no significant influence on the post-test scores of the Understanding test.

Then, we used the analysis of the Paired-Sample t Test (Lin, 2014) to compare the influence on post-test scores by each medium. In the animation group, the significance value was 0.008(p = .008) which was below 0.05, and the average post-test score was higher than the average pre-test score, indicating that watching animations can significantly improve the understanding of science. In the educational video group, the significance value was 0.03(p = .03) which was below 0.05, and the average post-test score was higher than the average pre-test score, indicating that watching educational videos can significantly improve the understanding of science. And in the science comic group, the significance value was 0.047(p = .047) which was below 0.05, and the average post-test score was higher than the average pre-test score, indicating that reading science comics can significantly improve the understanding of science.

Integrating the above data shows that no matter what kind of media can improve the participants' understanding of science.

Brief Summary

To summarize the above results, we can know that the animation group get the highest average score in the two dimensions of Awareness and Enjoyment, and the science comic group have the highest average score in the Interest dimension. On the dimension of Understanding, the analysis results of the three media show no significant differences, meaning that there is no difference in the impact of the three media on the post-understanding test. Afterward, the Paired-Sample t-Test of each media was carried out. The results show that the P-value of each material is less than 0.05, and all of the average scores of the post-test are higher than the average score of the pre-test, meaning that each media has a significant improvement in student's Understanding. As for Opinion Formation, because the subjects are young, they may have insufficient life experience, insufficient scientific knowledge, poor language skills, etc., which results in very few answers, or more than half of the students did not answer. In conclusion, the third-grade students do not perform well in Opinion Formation.

https://doi.org/10.33225/BalticSTE/2021.115

Conclusions and Implications

The spread of COVID-19 has caused a high demand for online learning or self-learning at home. We focus on evaluating which media is most suitable for self-learning for the third-grade students. To effectively evaluate the learning effectiveness, this study uses the five aspects of response to science communication as the evaluation framework. These five responses are: Awareness, Enjoyment, Interest, Opinion formation, and Understanding.

In this research, three types of media have been discussed: animation, educational video, and science comic. The first two are network resources, while the last is physical books. Throughout the experiment, the teacher played the role of observer, and was no longer the transmitter of knowledge. Only in this way could it be in line with the self-learning situation. Finally, the results pointed out that after the students used the three media, the third-grade students had positive feedbacks on the three dimensions of Awareness, Enjoyment, and Interest, among which Awareness scored the highest. Next, this study analysed the influence of the three media on AEI. Among them, the animation got the highest score in the two dimensions of Awareness and Enjoyment, and the science comic group got the highest score in the dimension of Interest. As for the dimension of Opinion formation, because the third-grade students are relatively young and have insufficient life experience and scientific knowledge, the response is poor. Nonetheless, all three media can improve students' understanding of science, and there is no difference between them.

In summary, the three types of media showed the effectiveness of self-learning for the third graders. Especially the animations proved to be the most suitable for the third-grade children to conduct self-learning. For the older students, the media that is suitable for self-learning may be changed, which requires further research.

Declaration of Interest

Authors declare no competing interest.

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Received: *June 12, 2021*   Accepted: *August 12, 2021*

Cite as: Lo, Y. W., & Ku, C.-H. (2021). Exploring the effectiveness and impacts of different types of media in science learning. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 115-125). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.115

CHEMICAL VS. NATURAL: COMMON MISCONCEPTIONS

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Abstract

In the era of universal and compulsory education, in which attention is paid to the ability to think scientifically, there should be no room for unscientific views. However, unscientific theories often appear in the media, and they find numerous supporters. Therefore, it was decided to investigate which of the common beliefs about the "chemical vs. natural" pair are believed by Poles. And whether belief in unscientific myths depends on gender, age, level of education or its type. Checking these relationships will allow, inter alia, to evaluate the effectiveness of science education in Poland. Within 4 years, the beliefs of 2,473 people were examined. The obtained results show that the universality of education does not prevent misconceptions. There was also no correlation between the correctness of the answers to the questions on age, gender, education level or its type. It seems that the way science is taught should be completely modified in such a way that students can distinguish truth from myth.
Keywords: *science misconceptions, common beliefs, fake news*

Introduction

Today, in many countries, compulsory education is considered a right for every citizen. It aims to level out the educational differences between citizens and to provide a minimum level of knowledge for all citizens (Universal Declaration of Human Rights art. 26, Convention on the Rights of the Child art. 28). The main goal of the Europe 2020 strategy was also to increase the level of education of Europeans (increasing the proportion of people aged 30-34 with tertiary education in Europe to at least 40%). Recommendation of the European Parliament and the Council of the European Union on Key Competences for Lifelong Learning (2006, 2018) describes in detail what competences Europeans should possess upon leaving school.

One of them is the so-called scientific competence. They refer to the ability and willingness to use existing knowledge and methodology to explain the natural world, formulate questions and draw evidence-based conclusions. In the case of the natural and exact sciences, the necessary knowledge covers the main principles governing the natural world, basic scientific concepts, theories, principles and methods, as well as an understanding of the impact of science and human activity on the natural world. These competences should enable individuals to better understand the benefits, limitations and risks of scientific theories and applications in societies in general (linked to decision making, values, moral issues, culture, etc.). Skills include understanding science as a process of studying nature through controlled experimentation, the ability to use technological tools

https://doi.org/10.33225/BalticSTE/2021.126

and devices and scientific data to achieve a goal or make a decision, or draw a conclusion based on evidence, and a willingness to give up one's own beliefs if they contradict new scientific discoveries. Individuals should also be able to recognize the necessary features of scientific conduct and be able to express the conclusions and reasoning that led to them. Competences in this area include attitudes of critical understanding and curiosity, respect for ethical issues and promoting both environmental safety and sustainability, in particular with regard to scientific and technological progress in the context of the individual, his family and community, and global issues.

It, therefore, seems that educated people should not believe in unscientific theories. However, despite the fact that in Poland the percentage of people with higher education is 45.7% (for the population aged 30-34) and 21% (for the group of people aged 25-64), many Poles believe in non-scientific, and many of them allow ads to deceive themselves.

International studies on the correlation between scientific knowledge and non-scientific beliefs most often concern the relationship between science and religion. So, i.a. belief in creationism or Darwinism (Allmon 2011; Bishop, 2007; Branch, 2008; Cornish-Bowden & Cárdenas, 2007; Brown, 2010; Plutzer & Berkman, 2008; Williams, 2009) or belief in the origin of the universe (De Carvalho, 2013; Fisher, 2006; Gleiser, 2005). Other non-scientific approaches are studied less frequently - one of them is chemical vs natural opposition (Rozin, et al. 2004; Li & Chapman, 2012; Chouakea & Friedman, 2012). And this problem is very common in everyday life. In colloquial conversations and publicity or ad, we meet the opposition: chemical or natural. However, is this opposition scientifically justified? From a scientific point of view, there is no difference between "natural" and "synthetic" versions of a chemical. Very often people think that "synthetic" chemicals (it means - chemicals made in a lab) are not as good for them as their "natural" equivalent. This is a complete misunderstanding of the basics of chemistry. Chemical molecules have the same properties, whether they were created in a laboratory or in a living organism. It seems strange that after 5 years or more of studying chemistry in school, misconceptions of this type can appear in people's minds. Therefore, it was decided to study the beliefs of ordinary people. It was decided to investigate whether belief in unscientific theories is common among Poles. And whether it depends on the level and type of education, age and gender of the respondents.

The main aim of the study was to check the effectiveness of science education in Poland. It was hypothesized that younger, better-educated people would not believe in unscientific myths. It was also assumed that people with natural science education would choose the correct answers more often than other people.

Research Methodology

To investigate the common beliefs of people about 'natural and chemical': drugs, cosmetics, food preservatives, etc., the research was conducted for a period of 4 years from March 2016 to February 2020.

The attitude of the respondents to 19 common beliefs - myths that often appear in the media was examined. People with secondary education should have no problem separating truth from falsehood. (In Poland, education is compulsory up to the age of 18.)

This article describes only the results of 7 myths about the conceptual opposition:

https://doi.org/10.33225/BalticSTE/2021.126

chemical - natural. These are the myths:

- All natural substances are healthy,
- Herbs are safer than medicines,
- Brown (cane) sugar is healthier than white sugar,
- Vitamin C helps with colds,
- The homeopathic remedies work,
- All chemicals are harmful,
- You can eat vitamins unlimitedly.

These questions were separated from each other by questions of a different type. The research was carried out in Krakow at the Pedagogical University. The study was attended by participants of open lectures (undergraduate, graduate and doctoral students, participants of 2nd and 3rd age universities, children participating in educational projects at our university), and people associated with them (e.g., family). A study of 2,473 people was conducted.

A questionnaire was used as a research tool. The respondents' task was to find out how much they agree with a given myth. The Likert scale was used as the measurement strategy. Because thanks to it you can get knowledge about the degree of acceptance of given views by the respondents. The survey had five answers: I fully agree, I agree, I have no opinion, I don't agree, I completely disagree.

The surveyed sample reflected the percentage of society in Poland. 62.8% of the respondents were women (which is consistent with the statistical data in Poland, women constitute 58% of students, and at universities of the 2nd and 3rd age they constitute as much as 86%). Most of the respondents were undergraduate (53.0%) and graduate students (28.5%). 12.1% were PhD students. 38.3% of respondents had a humanistic education, 37.3% strict education or technical and 13.5% natural science education.

Research Results

Table 1 summarizes the results of answering the questions. The analysis of the obtained data showed that in three (out of seven questions) the respondents answered incorrectly. And in one question they have no opinion. However, even in the questions where the majority of the respondents give the correct answer, the percentage of wrong and "undecided" answers is high.

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Table 1

Percentage of Answers to Selected Questions (Concerning the chemical / natural opposition).

Investigated myths	Responses of the study participants				
	I fully agree	I agree	I have no opinion	I don't agree	I completely disagree
All natural substances are healthy	11.73	26.20	9.14	35.30	17.63
Herbs are safer than medicines	13.30	34.86	20.30	25.03	6.51
Brown (cane) sugar is healthier than white sugar	22.12	44.36	19.17	9.70	4.65
Vitamin C helps with colds	32.15	49.09	9.83	7.04	1.90
The homeopathic remedies work	5.05	15.00	56.41	12.58	10.96
All chemicals are harmful	4.89	14.56	19.69	41.57	19.29
You can eat vitamins unlimitedly	4.08	9.38	12.05	39.06	35.42

Note: Responses considered correct are shown in bold. The most common answer appears on a grey background.

The most correct answers were given to the question: "You can eat vitamins unlimitedly". However, even in this case, the percentage of people who disagreed with this opinion is around 25%. The second question with the highest number of correct answers was: "All chemicals are harmful". However, in this case, as many as 39% of respondents did not indicate the correct answer. The attitude of people who "agree" to people who "strongly agree" is also different (for the vitamin C question it is 1.1 and for the question of the chemicals 2.2). The third question with a greater percentage of correct answers than the others is: "All natural substances are healthy". However, in this case, the percentage of people not choosing the correct answer is very high (about 47%). In this case, the ratio of people who "disagree" and "strongly disagree" is 2.0. Among the three questions that most of the respondents answered incorrectly, the question "Vitamin C helps with colds" had the most incorrect answers.

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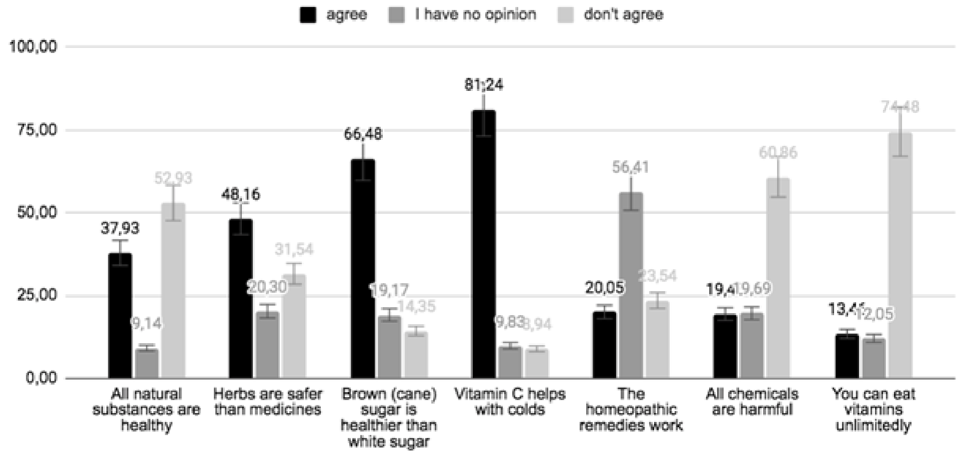
Figure 1
Percentage of Grouped Answers to Particular Questions



Note: (answers "I agree" and "I strongly agree" were grouped with the answers "I agree" and answers "I disagree" and "I strongly disagree" were grouped with the answers "I disagree").

The Spearman coefficient was calculated for the obtained data. In the part concerning the respondents, a moderate, positive relationship between the age of the respondents and their education (r_s = .53) and a weak relationship between sex and the type of education (r_s = .27) were obtained. In none of the seven questions, a correlation was found between the type of answer to the question and gender, age, education, and type of education. It was found moderate dependencies between the answers to the questions:

- All chemicals are harmful: You can eat vitamins unlimitedly (r_s=.46);
- All natural substances are healthy: All chemicals are harmful (r_s=.44);
- All natural substances are healthy: Herbs are safer than medicines (r_s=.41).

Weak relationships were found between the answers to the questions:

- All natural substances are healthy: You can eat vitamins unlimitedly (r_s=.34);
- Brown (cane) sugar is healthier than white sugar: Herbs are safer than medicines (r_s=.26);
- Brown (cane) sugar is healthier than white sugar: Vitamin C helps with colds (r_s=.26);
- All chemicals are harmful: Herbs are safer than medicines (r_s=.26).

No correlation was found between the answers to the remaining questions (Table 2).

Table 2
Spearman's Coefficient for Individual Pairs of Questions

	All natural substances are healthy	Herbs are safer than medicines	Brown (cane) sugar is healthier than white sugar	Vitamin C helps with colds	The homeopathic remedies work	All chemicals are harmful	You can eat vitamins unlimitedly
All natural substances are healthy		**.41**	.18	.08	.14	.44	.34
Herbs are safer than medicines	.41		***.26***	.17	.19	***.26***	.17
Brown (cane) sugar is healthier than white sugar	.18	.26		***.26***	.14	.11	.04
Vitamin C helps with colds	.08	.17	***.26***		.13	.03	-.05
The homeopathic remedies work	.14	.19	.14	.13		.16	.14
All chemicals are harmful	**.44**	***.26***	.11	.03	.16		.46
You can eat vitamins unlimitedly	***.34***	.17	.04	-.05	.14	**.46**	

Discussion

The results obtained show that, in the opinion of the general public, there is a belief that natural substances are superior to synthetic (chemical) substances in terms of effectiveness and safety in human health matters, although this is not true. Toplis (2002) obtained similar results to those obtained in these studies. It seems that the influence of the media promoting products containing the so-called natural substances as pro-health products have a great influence here. For example, Valkenburg et al. (2016) write about the power of the media on human attitudes and beliefs.

However, no influence of the degree of education or its type on the beliefs of the research participants was noticed. Similar results, i.e., the lack of influence of the level of education on people's attitudes (in this case, regarding climate change), describe Funk (2017) in the article *How much does science knowledge influence people's views on climate change and energy issues?* Similar research results were obtained by Impey et al. (2012). It seems that the summary of the considerations in the article "Belief, Knowledge, and Science Education" (2001, p. 349) still remains valid: "... we must shed light on this subject from a variety of sources — theoretical and empirical, philosophical and psychological — to advance our understanding of knowledge and beliefs and their influence on science learning".

Perhaps the explanation of the facts of belief in unscientific myths, despite the acquired scientific knowledge, can be found in the laws of Jost (1897). Although these laws were made a long time ago, it seems they are still valid today.

The first law states: *As time goes on, the power of associations of the elders weakens more slowly.* So, after many years, a person remembers the original associations associated with a given concept. So, for example, non-scientific explanations of parents or grandparents or information from advertising. That is why it is so important that the first explanation that a child meets in the process of environmental education is correct.

The second law states: *If two associations are of equal strength but one is older than the other, then the repetition will favour the older association more*.

This law also indicates the importance of the first connotations associated with a given concept. As the first associations with natural phenomena remain in memory for the longest time, their improper shaping may lead to a negative transfer at later stages of education and misconceptions in adulthood.

Conclusions and Implications

The obtained results indicate that a large percentage of the society does not have basic knowledge about the health properties (or harmfulness) of natural and synthetic substances. Despite the fact that in the Polish core curriculum for Nature, Biology and Chemistry, we can find many topics related to this issue. For example: In the core curriculum for elementary school for the subject Nature there is an entry: the student describes the effects of substances harmful to health, recognizes poisonous plants and poisonous animals. The core curriculum for Biology includes the entire section on "Chemistry of life", where attention is drawn to the lack of distinction between substances of natural origin and synthetic substances - obtained in a laboratory. And in the section "Digestive system and nutrition" is discussed, inter alia, digesting sugars and using vitamins. In the core curriculum in Chemistry, in the section "Chemical substances of biological importance", the properties of the substances that are the main components of everyday products are described. And in the section "Water and water solutions", the student performs calculations using, among others, concepts: solubility, percentage concentration. Therefore, it seems that after completing primary school education, the student should acquire knowledge that would allow him to correctly answer the questions asked in the questionnaire. However, as the results show, this is not the case.

The obtained results are a big challenge for people responsible for education, including teachers. The results show that non-scientific ideas are widespread among peo-

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ple and resistant to standard teaching methods. The question then arises: How and what to teach students to become informed citizens who vote / choose wisely on science and technology?

There seems to be some action to be taken to combat unscientific myths and to ensure that scientific thinking is at the heart of our teaching. Policy makers and curriculum developers must ensure science education as early as possible in kindergartens or primary education. False, unscientific perceptions instilled by the media or parents and naturally occurring in younger children will be very difficult, if not impossible, to correct at a later date. Curriculum makers and policymakers should also introduce a discussion and explanation of the most damaging anti-science myths into curricula.

Children in kindergartens and schools should be taught the 'scientific reasoning', for example by making extensive use of the IBSE or learning to discuss and argue. Teachers should be given the tools to combat unscientific theories, as well as a way to deal with those who hold such views. Scientists should be more involved in educating the public. They should avoid inappropriate and imprecise language; they should react when unscientific myths appear in the media. Working together can help prevent science misconceptions.

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Received: *June 11, 2021* Accepted: *August 10, 2021*

Cite as: Nodzyńska, M. (2021). Chemical vs. natural: Common misconceptions. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 126-134). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.126

TECHNOLOGY MAJORS' METHODOLOGY EDUCATION: COMPARING APPROACHES FROM TWO COURSES

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Abstract

The National Defense University (NDU) trains officers to develop their academic and professional skills. To accomplish this, the university offers two mandatory courses on methodological training for military technology students for master level education. The first course was theoretically oriented, and the second course was practically oriented. These both master-level methodology courses emphasize practice oriented mathematical skills, which officers use in their operative decision-making and statistical analysis. This study focuses on student-centered learning methodologies linked to teachers' observations from current and previous course implementations. Results in this study described the outcome from the first run of the revised curriculum. We collected data from students' course reports and the university's standard student evaluation of teaching (SET). According to the SET, the course 2 which was practically oriented course, where groups worked on more significant projects gained higher value among students. In conclusion, we recommend that teachers continue using student-centered learning methodologies to technical students as much as possible. Theoretically underscored courses should also contain more practical examples.

Keywords: *distance education, flipped learning, learning by doing, research methodology, student-centered learning*

Introduction

Theoretical knowledgebase is an essential aspect of technical teaching. However, in mathematics courses theoretically oriented courses require intense content design to be inspiring for students. Is it just about enhancing students' thinking skills, particularly abstract thinking? As late as the early 20th century, for about 50 years, Neovius-Nevanlinna mathematics textbooks were used almost exclusively in high schools. These books were considered consistent but demanding (e.g., Lehto, 2004). At that time, learning outcomes were typically such that one-third of students did not even reach the accepted grade. According to Nevanlinna (2021) the learning goals implemented in these textbooks were possibly too abstract for school children at that time. Nowadays mathematical knowledge is an essential component of experimental research. It is not merely a tool, but a vital part of exploratory questioning and a general methodological approach used in both quantitative and qualitative research (Aczel, 2006). Earlier in NDU, in officers' methodology education, master-level students appreciated a short, one-day-long intervention experiment around Word Math Day (Rissanen & Mutanen,

https://doi.org/10.33225/BalticSTE/2021.135

2019). In general, master-level technical students in NDU are open to any non-traditional math education.

In 2020, NDU's curriculum for master students changed a little bit, and some courses merged. The standard general line only has subject specification for the master thesis and formal support for discipline-specific knowledge linked to the thesis. According to the update in the curriculum, the Department of Military Technology gives two research methodology courses that support each other. This article presents those two updated formally Bologna process-based military technology courses where mathematical knowledge and practical skills are major learning items. The first course gives basic knowledge about traditional statistical analysis tools and includes a short session on how to make research in general. The second course teaches tools that would help to evaluate research settings. The preliminary modeling usually works as an advising tool during technical research. Therefore, the first course is more formal and theoretically oriented than the second course. This study aims to understand how students responded towards each of the two research methodology courses, namely *Methodology course 1* (theoretically emphasized distance learning and class learning course) and *Methodology course 2* (practically emphasized distance learning alone*)*. While the first course is more theoretically oriented, the second one is more oriented towards the technical aspects of practical research methodology. As the COVID-19 pandemic changed routines, the first course used more lecturing, while the second course employed more distance education principles.

Research Aims and Questions

The purpose of this study was to investigate the learning efficiency and also student satisfaction in general between these two courses.
RQ 1: Students 'attitudes towards mathematics as a research method and how do students' responses vary between these two courses?
RQ 2: How gained results of student responses should be noticed in future course design?

Theoretical Frames

Student-centered Learning

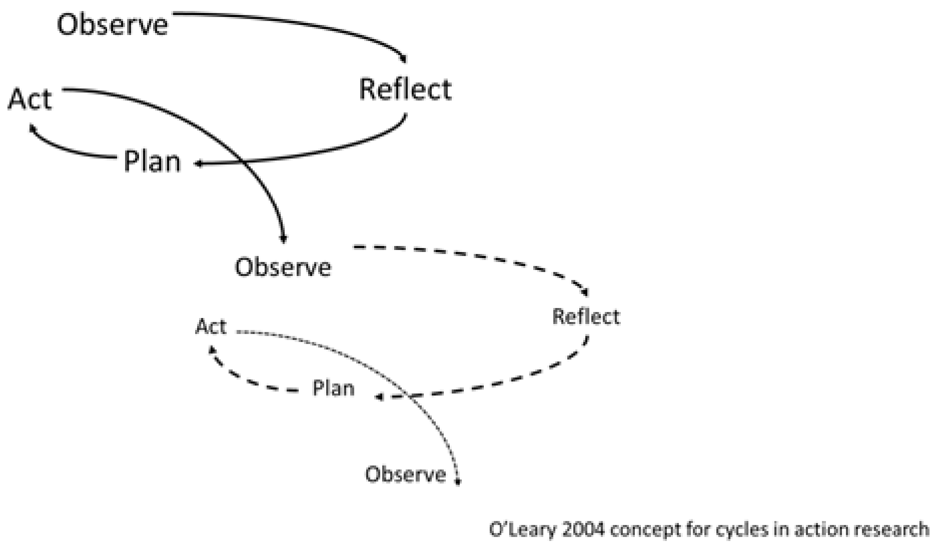
In student-centered settings, the responsibility for learning shifts naturally falls to the student (Wright, 2011). Students cooperate and take intense responsibility for their studies. Master-level students majoring in scientific subjects on NDU's technology program have different (individual) instructional needs. Therefore, the current study explores how relatively practice-oriented courses affect students' motivation and attitudes towards physics and technology as professional tools. On the other hand, the more traditional starting course would be a good reference for the study. Both courses include support for individual learning.
The literature suggests that student-centered learning can be approached e.g., using project-based learning (PBL). In the 21st century, this concept is used to revise curriculums. With a student-centered learning approach, students can experience real-life situations inside the classroom (or equally in their distance learning premises). Instructors are supporting

students on their journey to achieve learning. At all academic levels, small groups or teams working on projects are a mandatory arrangement. However, this arrangement alone does not allow higher levels of critical thinking. A traditional "one-size-fits-all" approach will not work for all types of education (Zmuda, 2009).

Action Research

Action research encourages researchers to participate in everyday life of the focus organization. Attendance combines with and influences subject analysis (Kemmis & McTaggart, 2013). Processes are not as straightforward as the sequential parts of independent design, operation, observation, and reflection. The described modules may overlap, and the original plans may become irrelevant based on experience and new information. Activity-related research can be reflected as an experiential learning approach, with sophisticated methods and enhanced knowledge interpretations based on the understanding of previous cycles (O'Leary, 2004; see Figure 1).

Figure 1
Action Research Cycle. Ideas of Continuous Research and Enhancement



Flipped Learning and Distance Education

A case study is a way of conducting research. It can be called a qualitative research approach, but a case study is not synonymous with qualitative research. The case study approach is not in itself a standalone research method. It isn't easy to give a general or comprehensive definition of a case study because there are different types of case studies (Crowe et al., 2011). In this work, we use it as a research strategy.

The flipped classroom refers to teaching with active and blended learning styles. The learning material is provided before any handling in lectures. This technique leads to integrating face-to-face and online teaching techniques enabling students to engage in meaningful and communicative learning and critical problem-solving. Therefore, course instructors may act as facilitators, guiding students in the discussion individually or in groups during class time. The implementation of flipped learning in a higher education course improved students' achievements and attitudes towards learning (e.g., Garrison & Akyol, 2009).

Ganesh (2021) presents how flexible a Moodle platform can be for this type of flipped learning. In his experimental videos and other study materials, he distributed texts through MOODLE platform. Learning targeted student-centered learning was organized underlining working in pairs or small teams.

Distance education has a long tradition, especially in Australia and the US Navy (e.g., Arenas, 2005). Due to the sudden and life-threatening COVID-19 pandemic, a large part of traditional university education has stopped. In Italy, Giovannella (2021) studied how the rapid transformation to distance education as the only choice, affected students' opinions. Although students seem to miss physical campus activities, the switch from physical to virtual environment was taken in a positive way. Moreover, a large part of the present generation of university students seems to be ready for novel educational activities.

Research Methodology

Data Collection

We used standard local SET questionnaires in PVMoodle for data collection, data comparisons, and data storage. Observations focused on common course impressions. In addition, we analyzed personal estimates of learning results, motivational aspects, and free text impressions. The questionnaires involved a 5-point Likert scale. When we combined the quantitative data from the questionnaires with the qualitative data—such as data gathered using open-ended questions, participant observations, and interviews—the questionnaires' validity improved, and our results became more accurate. For Figure 2, we selected only eight most analyzable questions from the standard questionnaire.

The answers gathered are to the following questions or notices:

1) I achieved the goals set for this course.
2) I was active during the course?
3) Was the overall ambiance during the course supportive of your studies?
4) How well did the instructors master the subject matter of the course?
5) Give an overall grade for the instructors.
6) Did you learn new information/skills?
7) Did the evaluation of this course support your learning?
8) Give an overall grade for this course.

The number of students who voluntarily participated in the evaluation was 21 for the course 1 and 12 for the course 2.

Research Material

Course implementation

Teaching in the first course (Hybrid course with class learning and distance learning)

The first course, which included research practice and statistical methods, was organized into two parts. According to the course plan (a detailed plan expressed in the weekly program), mathematical content and statistical methods were taught intensively in two-week period. Teaching methods included lecture teaching, illustrative demonstration examples, and voluntary and supervised practice. Instead of fully present or distant education, a hybrid version was utilized. Therefore, remote participation was possible but not too comprehensive. The assessment consisted of five sets of tests based on scored exercises (i.e., 23 calculation tasks), of which 60% of the maximum points had to be obtained for the approved performance. Along with the course progress, 21 out of 22 students passed this formative test. The one who failed had an accident which prevented further participation along the spring term. All students responded to the feedback questionnaire after the professor's reminder. This course aims to acquire the skills related to Pro Graduate research and consists of exercises and knowledge creation in group works. Observations from student evaluation of teaching (SET) data complemented this knowledge.

Teaching in the second course (distance learning)

The second course, which consisted of practical modeling methods and simulation tools, took place during spring term in three weeks period. The instructional structure of course 2 was similar to the previous years' simulation and modeling course, which had been carried out eight times with good feedbacks from students and with only minor modifications. It consisted of three overlapping teaching methods, namely distance lectures, supervised exercises, and unsupervised exercises. At the end of the course, student groups presented their unsupervised exercises. The final report consisted of documentation and the functional version of the group's own specific modeling realization. The course used simulation and mathematical modeling as a research method.

The first week (in the 3 weeklong course module) content was about random numbers and distributions, IF-THEN structure and reasoning, Lanchester equations, Markov chain, Monte Carlo simulation, and Queuing theory. Two distance lectures on machine learning, artificial intelligence in the Defense Forces, and general machine learning methods and the skills required for their use were also presented. Learning exercises called seminar work were also published. Most of the seminar work topics came from the students themselves in connection with their master's theses.

Course content in the second week was about mathematical models to support decision-making, value tree analysis, analytical hierarchy process (AHP), and optimization methods.

In the third course week, students focused on completing shared homework as well as seminar work. Students were given personal guidance using remote connections and according to their research needs. By the end of the course, the exercises were complete. In the last teaching event, the students presented their seminar work in groups.

https://doi.org/10.33225/BalticSTE/2021.135

The course aims to help students understand the methods taught and apply them. Based on the questions actively asked by the students, the work done in the final seminar, and the student feedback, we can conclude that the goals set at the beginning of the course have been met.

Learning took place remotely using Zoom and PVMoodle. Also, additional communication was done via Skype and email. Using Zoom for cloud-based video conferencing is not new (e.g., McCoy, 2015), but due to its flexibility to enhance distance education during the COVID-19 pandemic, both courses in this study utilized where applicable.

Research Results

Analysis Based on Student Feedback

Students are familiar with the National Defense University's standards for student evaluation of teaching (SET). However, the validity of student evaluation of teaching (SET) in universities depends on which purpose it has been utilized. An early and limited study made in the UK context (Shevlin et al, 2000) demonstrates that teaching ability can influence evaluations. Moreover, they name other factors like student profile and the physical environment. To overcome some of the side effects, they included new elements related to the lecturer's charisma. With a student-centric approach, opinions of teachers' charisma become less critical. On the other hand, e.g., Athiyaman (1997) claims that student satisfaction and service quality could be a way to construct a value from the SET data type of information.

Feedback data from students with SET provides the necessary information for instructors on how to streamline teaching protocols, but it gives only a few tools for making significant educational improvements. Therefore, development work in this field requires more than just empirical evidence of learning results and students' wishes and opinions. Technology development also offers this era new opportunities to organize education in a rewarding way, and genuine innovations in this area require more than gathered formal feedback. The responsibility to re-engineer education creatively creates a continuous challenge for instructors and organizations. For that purpose, student reports and written statements in SET are indirectly utilized.

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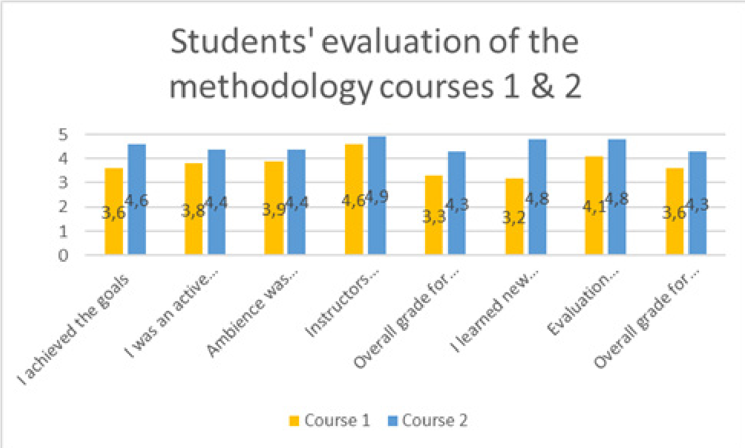
Figure 2
Students' Evaluation of the NDU's Research Methodology Courses 2021 (Course 1, N:21; Course 2, N:12)



Discussion

Student feedback from Course 1 was generally little over average in factors describing student activity. The professional skills of teachers were good. On the other hand, based on the feedback survey, it is worth adding mathematical details to the teaching material in the learning material portal. This is a clear development plan for statistics in the subsequent implementation. The feedback from the Courses 1 and 2 was at an excellent level. However, scheduling is still worth refining for the courses. Both courses included exercises. The statistical methodology in both courses was demanding but also relatively straightforward to apply. On the other hand, according to students, modeling had more connections to daily life. But also, the teachers needed more detailed mathematical formulation of the set problem or intermediate processes towards the solution. According to the data presented in Figure 2, the overall attitude toward learning was higher in the later course (2, practically oriented student-centered course). Due to nine lacking answers in course 2, the numeric data can be utilized for profiling with other data. According to the SET data with open question answers, course 2 was perceived more student oriented. In this course, students could suggest their final works and worked collaboratively under their teacher's supervision. Because of this, students appreciated it more.

Conclusions

A balance between rigor and practice is essential. Students at NDU have always wished for more practice-based examples. Therefore, it is understandable that they prefer a course that emphasizes practice. Distance learning does not mean less student satisfaction. Results showed that students were generally more interested in practice-oriented student-centric education. This does not mean that theoretical education is less valuable. On the contrary, the results showed that educators could inspire students to value theoretical knowledge if they demonstrate the practical applications of such knowledge. Theoretically emphasized course (course 1) should also include more real-life related examples. However, more research is required to deliver theoretical knowledge in an inspirational and student-friendly manner effectively.

Acknowledgments

The authors appreciate Adjunct Professor Juha Honkonen for his co-operation and his description of mathematical instruction information for the statistical methodology. We would also like to thank professor Juha-Matti Lehtonen for reminding students to give their feedback about course 1.

Declaration of Interest

Authors declare no competing interest.

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Received: *June 16, 2021* Accepted: *August 11, 2021*

Cite as: Rissanen, A., & Saastamoinen, K. (2021). Technology majors' methodology education: Comparing approaches from two courses. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 135-143). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.135

ALGORITHMIC APPROACH TO QUANTITATIVE PROBLEM-SOLVING IN CHEMISTRY

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Abstract

Examining students' inclinations to use algorithms and rules to solve a task was a fruitful area of research in chemical education in the last four decades. This research aimed to examine whether students read the task request carefully, considering its meaningfulness, or they approach it mechanically, applying a set of algorithms by default. The research sample consisted of students majoring in chemistry teaching at the University of Novi Sad, Faculty of Sciences who were in their final year of bachelor studies. The study was conducted during two academic years. The main instrument consisted of five quantitative problems, and each of the problems contained deceptive information that made the calculation nonsensical. The results revealed that most students applied an algorithmic approach without paying attention to the meaningfulness of the task requirements. Additionally, it has been shown that students rely heavily on memorizing formulas without a proper understanding of underlying concepts.
Keywords: *algorithms, conceptual understanding, quantitative problems*

Introduction

One of the most important outcomes of chemical education is the development of conceptual understanding (Rodić, 2018). There are many definitions of conceptual understanding suggested so far which are mostly intuitive. This study relies on a definition proposed by Holme et al. (2015) which resulted from extensive research and meets the most comprehensive requirements of the chemistry education community. It describes the conceptual understanding across five dimensions: (i) *transfer* (student's ability to apply main ideas in chemistry to novel chemical situations), (ii) *depth* (reasoning beyond memorization and algorithms), (iii) *prediction* (ability to explain behaviour of chemical systems), (iv) *problem solving* (reasoning involved in solving problems) and (v) *translation* (ability to translate between scales and representations). However, although conceptual understanding is a desirable learning outcome, in practice, students are far more in favour of the algorithmic approach. There is strong evidence that students are inclined to use algorithmic problem-solving strategies without engaging in conceptual reasoning (Cracolice et al., 2008; Lazenby & Becker, 2019).

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This may be related to the fact that school chemistry around the world is organized in such a way that it is subordinated to the success of students in the final examinations (Stamovlasis et al., 2005). Therefore, teachers are often forced to dedicate the vast majority of their teaching time to practising very complex calculations. In that way, students become experts in calculations, and at the same time, they do not understand the conceptual basis of the content itself.

This research aimed to examine whether students – future chemistry teachers from Novi Sad, have a mechanical/algorithmic or conceptual approach to solving quantitative problems in chemistry. The main idea was to find out whether students read the request carefully, considering its meaningfulness, or they approach it mechanically, applying a set of algorithms by default. Accordingly, the following research questions were set up:
RQ 1: Do students possess declarative knowledge regarding some selected concepts?
RQ 2: Do they activate that knowledge during the problem-solving process, or such knowledge is dysfunctional?

Research Methodology

Study Sample

Two generations of future chemistry teachers took part in this research. Both groups were in their fourth (final) year of bachelor studies. There were 22 students, 12 in the academic 2016-2017 and 10 in the academic 2017-2018. Of the total sample, 3 students were male and 19 were female. Although the total sample was 22 students, it is representative since it encompasses all students of the target group (students majoring in chemistry teaching at the University of Novi Sad) over two academic years. In addition, this study has mainly a qualitative character and the sample cannot have much impact on research outcomes.

All respondents agreed to volunteer in the research. They were explained that their answers and results are going to be used for research purposes without any compensation and that they can opt-out of the study at any point.

Research Instrument

Two instruments were used in the research. The first instrument (T1) was a paper and pencil test with four multiple-choice tasks, which were designed to provide the answer to RQ1. This test examined declarative knowledge such as the knowledge of insoluble compounds and metals in water, the relative position of metals in activity series, and molar volume. T1 questions are given in Box 1.

Box 1. T1 questions

Q1. Which answer includes all the following that are insoluble in water? Circle the letter of the correct answer.

a) $AgCl$, $NaNO_3$, $Ba(NO_3)_2$ b) $AgCl$, $BaSO_4$, $Al(OH)_3$

c) $Ba(NO_3)_2$, $AgCl$, KCl d) KCl, $AgCl$, $Al(OH)_3$

Q2. Circle the letter of the correct answer. Which of the following metals does not dissolve either in hot or cold water, under standard pressure?

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a) Al b) K c) Mg d) Ca
Q3. Circle the letter of the correct answer. Which of the gases bellow is product of the reaction between copper and concentrated sulfuric acid?
a) H_2 b) H_2S c) SO_2 d) H_2O
Q4. Circle the letter of the correct statement.

The second instrument (T2) was a test consisting of five conceptual tasks (CT). It was designed to provide an answer to RQ2. Each task contained a piece of deceptive information which made the calculation senseless. Namely, students were requested to calculate the molar concentration of the solution, but the compound given was insoluble in water; to calculate the volume of a product, but the reaction was impossible; to calculate the molar volume of a solid substance; to calculate pH value of the solution formed by dissolving the metal in water, but the given metal was insoluble in water. T2 tasks are shown in Box 2.

Box 2. T2 questions
CT1. Calculate the molar concentration of the solution obtained by adding 15 g of silver chloride to 50 cm^3 of distilled water. (STP)
CT2. Calculate the volume of hydrogen formed in the reaction of 6.35 g of copper with the corresponding amount of sulfuric acid. (A_r(Cu)=63.5; A_r(H)=1; A_r(S)=32; A_r(O)=16) (STP)
CT3. What is the pH of a solution formed by the addition of 0.1 mol of aluminum to a 10 dm^3 of water? (A_r(Al)=27) (STP)
CT4. How many grams of barium sulphate should be added to 150 g of distilled water to prepare a 10% solution (A_r(Ba)=137) (STP)
CT5. What is the volume of carbon needed to react with the appropriate amount of oxygen to produce 2.24 dm^3 of carbon dioxide? (A_r(C)=12; A_r(O)=16) (STP)

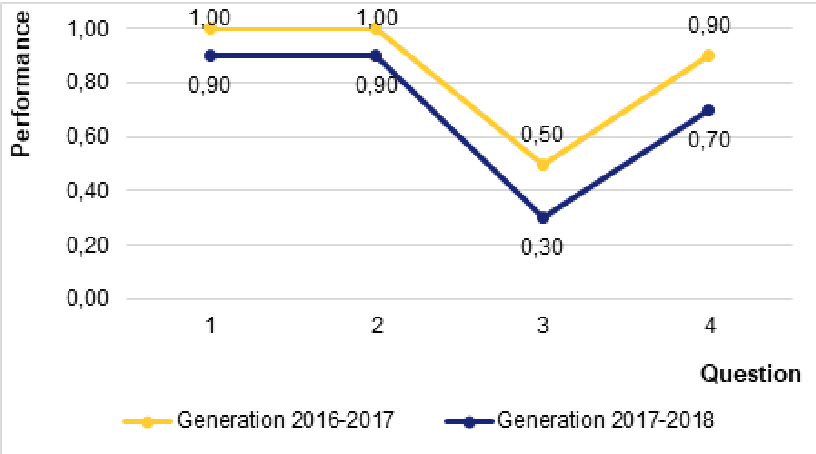
Testing was conducted in 4 phases: (i) February 2017 (T1, generation 2016-2017), (ii) March 2017 (T2, generation 2016-2017), (iii) February 2018 (T1, generation 2017-2018) and (iv) March 2018 (T2, generation 2017-2018). Time for solving T1 and T2 was unlimited, and all the tests were carried out anonymously. Data processing was carried out in the program Microsoft Office Excel.

Research Results

Results of T1

Figure 1 shows the T1 results for both generations of students. Based on the results, it is evident that students in a very high percentage were successful in solving the first, second and fourth questions, which were related to the recognition of compounds and metals insoluble in water and the molar volume of gases. The lowest achievement was accomplished in the third question, where SO_2 was expected to be recognized as a product in the reaction of copper and concentrated sulfuric acid. High achievements on T1 questions were expected, as students were in their final year which means they had the expected declarative knowledge with certain exceptions (Q3). Such results were a precondition for the next stage of research, that is, for conducting T2.

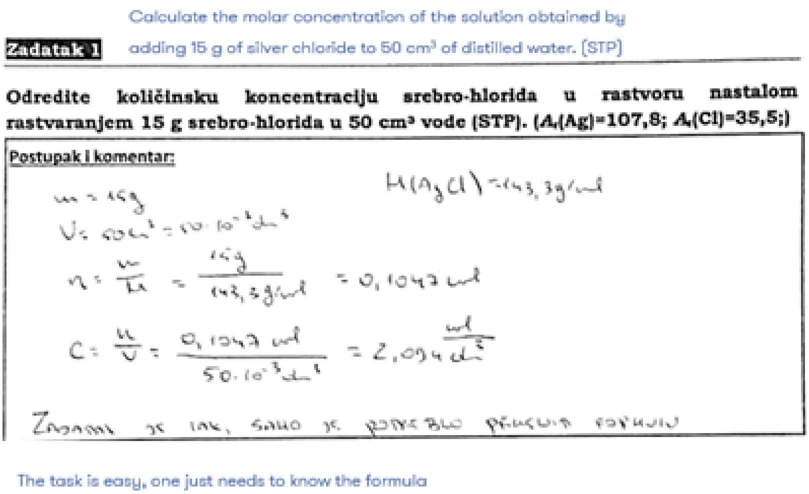
Figure 1
Achievements on T1



Results of T2

The results of T2 will be analysed qualitatively on the selected examples of tasks. In CT1, students were asked to calculate the molar concentration of silver chloride in the solution formed by its dissolution in water. Although by solving Q1 on T1 students showed that they know that silver chloride has low solubility in water, in CT1 they ignored this information. All students in this study tried to respond to the request of the task by applying a standard formula for calculating the molar concentration of a solution, and none of the students noticed the deceptive information. Figure 2 shows an example of a student's response.

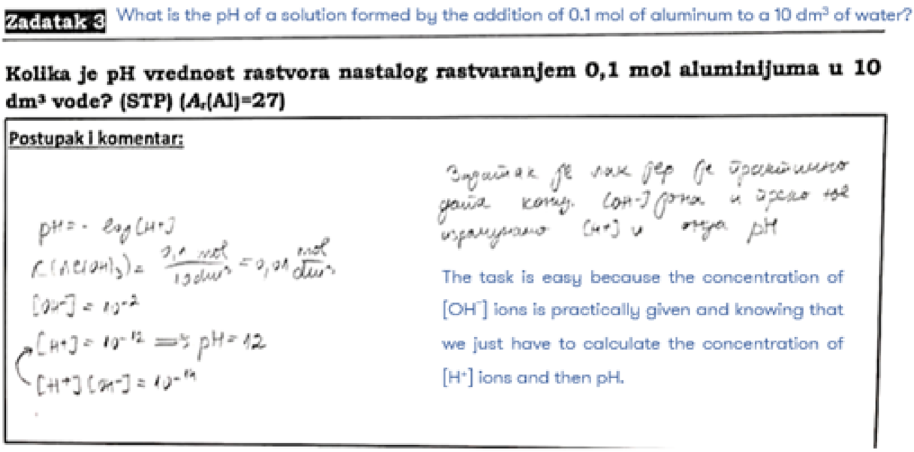
Figure 2
An Example of a Student's Response on CT1



In CT 3, it was necessary to calculate the pH value of the solution, which is formed by dissolving aluminum in water. In this task, the students did not pay attention to the key information - aluminum that does not dissolve in water. Surprisingly, none of the respondents linked the insolubility of aluminum in water with its application in everyday life, for example in the production of aluminum packaging used for storing foods such as milk, yoghurt and other products with a high percentage of water in their composition. On the other hand, the students were very successful in solving Q2 where they recognized aluminum as a water-insoluble metal. This means that students have declarative (factual) knowledge, but that this knowledge is rather passive. An example of a student's response on CT3 is provided in Figure 3.

Figure 3

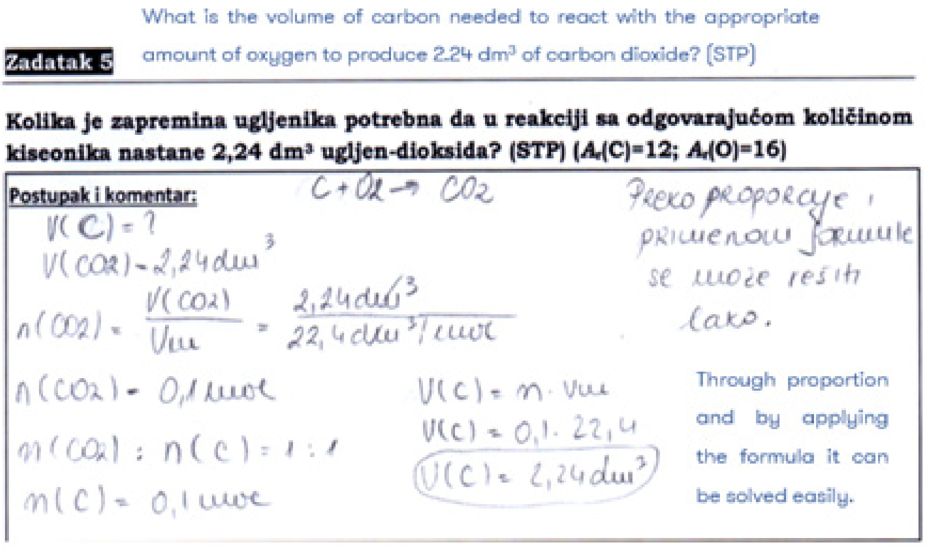
An Example of a Student's Response on CT3



In CT5, it was necessary to calculate the volume of carbon, however, since carbon is an element in a solid-state under STP, it was not possible to calculate its volume using only the data given. The students overlooked this fact and performed the calculation assuming that the volume of 1 mole of carbon is 22.4 dm^3 as if the carbon under STP is a gas (figure 4). As with the previous questions on T1, the students were successful in solving Q4 where they showed that they knew that the value of 22.4 refers only to gases. However, this knowledge was not applied in CT5, which once again confirmed that when solving quantitative problems, students give preference to algorithms over logical reasoning.

https://doi.org/10.33225/BalticSTE/2021.144

Figure 4
An Example of a Student's Response on CT5


What is the volume of carbon needed to react with the appropriate amount of oxygen to produce 2.24 dm³ of carbon dioxide? (STP)

Zadatak 5

Kolika je zapremina ugljenika potrebna da u reakciji sa odgovarajućom količinom kiseonika nastane 2,24 dm³ ugljen-dioksida? (STP) (A_r(C)=12; A_r(O)=16)

Postupak i komentar:

C + O2 → CO2
V(C) = ?
V(CO2) = 2,24 dm³
n(CO2) = V(CO2) / Vm = 2,24 dm³ / 22,4 dm³/mol
n(CO2) = 0,1 mol
n(CO2) : n(C) = 1 : 1
n(C) = 0,1 mol
V(C) = n · Vm
V(C) = 0,1 · 22,4
V(C) = 2,24 dm³

Preko proporcije i primenom formule se može rešiti lako.

Through proportion and by applying the formula it can be solved easily.

Analysis of Students' Comments

As can be seen in Figures 2, 3 and 4, students were expected to give a brief comment on each CT related to the solving procedure. Students were instructed to provide a comment in a blank field reporting on how difficult or easy it was to resolve a task. Additionally, they were asked to reflect on each CT; whether the request was clear and logical to them, or they found some information missing, misleading etc.

Selected comments:

- The task is easy, one just needs to apply the formula.
- The task is easy if you know the formula.
- The task is not a problem if the formulas and the value of V_m are known.
- The task is easy because the concentration of [OH$^-$] ions is practically given and knowing that we just have to calculate the concentration of [H$^+$] ions and then pH.
- Extremely easy because one just needs to substitute known variables into the formula.
- The task is easy because by applying the formula it can be solved in one step.

- I can't remember the formula.
- I'm not sure if I used an appropriate formula.
- The task is not difficult, but I can't recall the formula.
- I forgot the exact formula. I think it's easy, but I can't remember the formula I need to apply.
- I can't calculate, because I haven't used that formula for a long time.

What all comments have in common is the word formula. Most of the students were very confident that they resolved the tasks correctly because they knew the appropriate formula. From their comments it is clear that they apply an algorithmic approach – they read the text of the task, extract the data, write the appropriate formula and substitute known variables into the formula. At the same time, they do not pay enough attention to the meaning of the requirements.

Conclusions

Based on the results of T1, it can be concluded that students had certain declarative knowledge. All students who tried to resolve the tasks from T2 were using known formulas and algorithms. None of the students noticed the concepts that made the calculation nonsensical. Based on the comments, it can be concluded that students do not pay enough attention to the underlying concepts.

These results suggest that more attention should be paid to the conceptual underpinnings and less to a drill that is based on solving a large number of calculations by mechanical learning of steps and by rote memorization of procedures. Students must understand the meaning of calculations and their relation to everyday life. For this purpose, it is convenient that tasks contain an everyday life context that will enhance student motivation, thus enabling the acquired knowledge to be long-term and more functional.

Acknowledgements

The authors acknowledge the financial support of the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 451-03-68/2020-14/200125).

Declaration of Interest

Authors declare no competing interest.

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Received: *June 20, 2021* Accepted: *August 16, 2021*

Cite as: Rodić, D., Horvat,S., Rončević, T., & Babić-Kekez, S. (2021). Algorithmic approach to quantitative problem-solving in chemistry. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 144-151). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.144

CHALLENGES FOR PRE-SERVICE PHYSICS TEACHER EDUCATION IN A NORTHEASTERN BRAZILIAN STATE IN PANDEMIC TIMES

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Abstract

Pandemic has changed the way education has taken place in Brazil, which has occurred remotely. The classes have been taught in the public network especially through lives or WhatsApp. In this paper, the way in which the training activities of the supervised internship and the Pedagogical Residency in the teaching of Physics in schools took place will be addressed. As a result, the abundant use of new information and communication technologies was verified. Resources and methodologies such as digital platforms, simulators, gamification, among others, were used by pre-service teachers during supervised internship and / or Pedagogical Residency activities. With this, pre-service teachers were able to immerse themselves in the current school reality, better understanding how teaching has occurred in this period and to propose activities that could help to improve the quality of teaching offered in basic education schools and in the recycling of in-service teachers, as well as in the motivation of students, too.
Keywords: *pandemic period, pedagogical residency, physics teaching, supervised internship, teacher education*

Introduction

By the end of 2019, COVID-19 had rapidly spread to China and thus to the rest of the world (Albuquerque et al., 2020). With this, Brazil and the world are continually facing the social, economic, and emotional impacts of the pandemic. In Brazil, federal law no. 13,979 (2020), which provided for measures that could be adopted to deal with the public health emergency of international importance resulting from the coronavirus responsible for the 2019 outbreak, resulted in several other laws, both at the federal, as well as state and municipal levels.

Brazil is a country of continental dimension, composed of 27 Federative Units (FU), popularly known as states. There is a very large disparity between these UFs. Piauí, one of the Brazilian FUs and whose capital is Teresina, the city where the research was carried out, has a Human Development Index of 0.697 (IPEA, 2019), the third lowest among all Brazilian FUs and similar to that of Vietnam, well below Brazil's HDI, which is 0.778. In this state, in response to law no. 13,979, it can be highlight decree no. 18,884 (2020), which regulated the aforementioned law at the state level and determined the suspension of classes in the state public system and recommended the closure of other schools and Universities in the state, as well as churches, bars, restaurants, stores, etc.

https://doi.org/10.33225/BalticSTE/2021.152

Decree no. 18,901 (2020), determined the suspension of religious, commercial, aesthetic and sports activities in the state of Piauí. Social isolation was decreed with a ban on opening economic activities, closing schools and universities, non-essential commerce, and public leisure areas, among others, with the exception of essential activities, such as cleaning, health, safety, among others. With this, ordinance no. 343 (2020) that proposes replacing face-to-face classes with classes in digital media while the Covid-19 pandemic situation lasts. Through the ordinance, the Ministry of Education decides:

> "Art. 1st Authorize, on an exceptional character, the replacement of on-site subjects, in progress, by classes that use information and communication means and technologies, within the limits established by the legislation in force, by a higher education institution that is part of the federal education system, of which deals with art. 2 of Decree n. 9,235, of December 15, 2017 (Ordinance no. 343, 2020, p.01, author's translation)".

Most of the municipal governments adhered to remote education. Schools have had their classroom activities suspended and many states and cities have adopted the continuity of classes through the remote system. Thus, the new reality abruptly imposed opened up the need to revise the teacher training, in order to make them able to work in a dynamic world that requires professionals capable and adaptable to the new demands. In this way, one of the things that would need to be revised was the supervised internship (SI), in which the future teacher immerses in schools, being, therefore, a very rich moment of learning, which we will deal with in the next section.

Teacher Education, Supervised Internship and Pedagogical Residency

Supervised internship is, according to 1st article of law no. 11,788 (2008, author's translation), "supervised school educational act, developed in the work environment, which aims at preparing students for productive work who are attending regular education […]". This law adds in its items the internship is part of the pedagogical project of the course and aims the learning competences proper to the professional activity and the curricular contextualization, aiming at the development of the student for the citizen life and for the work. In SI the pre-service teacher carries out observation and teaching activities.

SI is seen by a lot of people as the practical part of the course. Pimenta and Lima (2015) have put SI as a theoretical and practical activity. So being considered, it is interesting that research is developed to optimize this moment. André (2015) has observed that there is a consensus in the educational literature, both in Brazil and abroad, that research is an essential element in the professional training of teachers. Severino (2008) affirms that one learns to research by researching and, during graduation, this research is carried out concretely in the Course Conclusion Monography (CCM) and in the scientific initiations. Rodrigues and Arroio (2018) have argued that the SI period can also be a fertile period to carry out research.

Pimenta and Lima (2015) have commented that SI is intended to approach reality, and the internship is not a practical activity, but a theoretical one, which implements the teaching praxis, which is the activity of transforming reality. The authors (idem) also comment research in the internship is a possibility in the training of the intern as a future teacher.

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In addition to the SI there is another possibility for the training of future teachers *in loco* who are taking the second half of undergraduate teacher formation courses, which is the Pedagogical Residency Program (RP). The RP is one of the actions that integrates the National Policy for Teacher Training and aims to induce the improvement of practical training in undergraduate courses, promoting the immersion of the student in the basic education school (CAPES, 2020). As in SI, in the RP the pre-service teachers perform observation and teaching activities.

In a similar way to residencies in the health area, in RP the resident stays for a while in the place of his future performance as a professional, which, in this case, is the school, under the supervision of an effective teacher in the area he studies, the preceptor. However, with the pandemic caused by COVID-19, schools and universities were closed and the training activities that took place during SI and RP were hampered. In the following section, it will be presented how the teaching is offered today in Brazilian schools.

The Teaching Offered Today in Schools

In the state of Piauí, according to a survey carried out by the Piauí State Department of Education - SEDUC / PI (Piauí, 2020a), 88.82% of students enrolled in this network are having access to remote activities in a virtual way or by printed material. Among these students, access is distributed in different ways. As shown in Table 1, the teaching contact ranges from WhatsApp groups, instrumental platforms for organizing class content (Google Classroom), through other means, for example, phone calls, email, etc. 11.18% of students in the state public network of Piauí still had no access to classes at the time of publication of the report (12/07/2020).

Table 1
Options for Remote Education Access in the Public Network of Piauí

Contact Source	WhatsApp Groups	Printed Material	Google Classroom	Others	No access
Percentage (%)	42.40	24.49	12.52	9.41	11.18

Source: (Piauí, 2020a)

Of those students who attend classes, there is a predominance of the use of cell phone applications as a means of access. This shows that a large portion of the population has access to cellular devices and that they can also be used in Education. In view of this, at the end of November 2020, the Government of the State of Piauí made available, according to news on its official page (Piauí, 2020b), more than 180 thousand internet chips to students from the state network, to guarantee access to digital platforms that provide video lessons and activities produced by teachers, such as Canal Educação, Pré-ENEM Seduc and the iSeduc Aluno application.

One of the main consequences of remote education during the pandemic was the change from the school environment to the home environment. Such a change was not expected even by teachers who already adopted online environments in their teaching methodologies. This brought about such a rapid and emergency change, almost obligatorily. At first, teachers and students had to adapt quickly to the use of digital platforms and new information and communication technologies (NICTs), which despite not being new, always faced challenges for their implementation, such as: the lack of investment in technologies in education; schools do not offer the minimum technological structure of pedagogical support to teachers and students; higher education courses that do not enable professionals to work using new technologies; in addition to the teachers' own resistance to work with these technologies (Soares-Leite & Nascimento-Ribeiro, 2012).

Teachers have become exposed to problems never experienced before (for the vast majority),

> "[...] for new problems, new answers, then the emergency to face COVID-19 has required updating and incorporation of new knowledge and technologies on the part of professionals who deal directly with suspects, confirmed cases and those who are in other care fronts. As well, remote work, distance education and telehealth, which were the targets of technical and ethical questions, become the means of maintaining services and attendance, permanent education, and social interaction (Falcão et al., 2020, p. 4, author's translation)".

In this way, teachers would need to become Youtubers by recording video-lessons and learning how to use video conferencing systems to adapt and develop new methodologies, to think about new ways of evaluating, and especially, to ensure the attention of students (Monteiro et al., 2012).

It´s known the year 2020 was atypical, due to the occurrence of the pandemic, teaching underwent several transformations, causing the methodologies adopted within the classrooms to be modified. As a result, teacher training at a higher level to work in basic education had to undergo adaptations, starting from a face-to-face teaching model to an already existing model of Distance Education (DE), but little used by education professionals. This type of distance learning provided a basis for the remote education adopted in the pandemic period, which has brought a new form of interaction between students and knowledge and brought them closer to technologies, that is, it has brought new channels of interaction between teachers and students and, also, a new teaching-learning evaluation process.

Thus, it was clear that part of education professionals was not prepared to take on remote learning, as the vast majority did not know how to use digital platforms or did not have the knowledge to handle them, due to the non-mandatory use in the classroom (Ribeiro Junior et al., 2020). Therefore, this lack of knowledge of many of the digital interfaces is due to the fact that subjects that teach and influence digital use in teaching are not offered in teacher formation courses. Another reason also for being associated with schools, for the most part, do not offer structure for teachers to apply digital teaching:

> "A survey launched in early April [2020] by the Innovation Center for Brazilian Education (Cieb) showed the basic education network's difficulty in finding solutions to face the Covid-19 pandemic. At the time of the study, 60% of the counties had no digital strategy to serve students during the period of social distance (Kochhann, 2020, author's translation)".

According to an interview with the director-president of Cieb Lucia Dellagnelo, "in municipal networks, more than 70% had not used any online tool or methodology with their students. They saw that teachers do not know how to use these tools well" (Kochhann, 2020, author's translation). Corroborating this, in a survey conducted with 52 teachers from different areas of the public and private education network in Piauí and Maranhão (another Brazilian FU, the second with the worst HDI) it was found that "[...] 52% of teachers have knowledge limitations in the use of educational technologies (text editing, internet research, video editing, among others), 27% need help from others, and 22% consider themselves self-sufficient" (Ribeiro Junior et al., 2020, author's translation).

With face-to-face education not possible, the solution was to bet on digital platforms so that teaching would not be stopped. Platforms and applications such as Youtube, Google Classroom, Google Meet, Zoom, WhatsApp, OBS Studio, among others, were essential for teachers to transmit knowledge, trying to minimize the losses of the school year. However, the difficulties become even greater when part of the students do not have access to such platforms, due to the lack of conditions to have good quality internet or devices that can access them.

> "Thus, considering the social function of the school in the pre-pandemic and post-pandemic, it is important to understand the use of educational technologies for basic education has potentialized new learning for the teaching staff (mainly), although the focus has been on student, for whom there has been double attention in an attempt to cushion the effects of social isolation and ensure the teaching and learning of students (Ribeiro Junior et al., 2020, author's translation)".

Pandemic brought about a great transformation in the lives of teachers and students, leaving as legacy the immersion of remote education as the main tool for education networks, both private and public. In the post-pandemic, it is believed hybrid education, part with distance learning and the other face-to-face, will be part of the daily education, as the school will continue to have its role of learning and socialization, however mixed with new technologies.

Given this, the following question came up: how to prepare future Physics teachers to carry out their teaching activities during supervised internship or pedagogical residency in basic education, in Teresina, Piauí during the period of social isolation? It is aimed, specifically, to understand how pre-service Physics teachers will be able to perform SI and RP activities remotely, acting in the way schools are functioning and helping to improve the performance and interest of students in the discipline of Physics in this pandemic period. Below, the methodology used to carry out the research.

Research Methodology

General Background

This study is an exploratory and qualitative research. Exploratory because it seeks to examine and discover a still unknown reality. This method mainly uses qualitative research techniques based on observations and interviews (Selltiz et al., 1987). The data were produced by conversations with the supervising teachers (identifying how the classes have occurred), proposing new activities and verifying the results of these activities through conversations and / or reports.

According to Liebscher (1998), to learn qualitative methods it is necessary to learn to observe, record and analyze real interactions between people, and between people and systems. This research was carried out with pre-service Physics teachers, who were enrolled in the supervised internship disciplines of teaching physics, or they were participating in the RP program both at the Federal University of Piauí (UFPI), located in Teresina. This research included pre-service Physics teachers at the University and in-service Physics teachers at the secondary schools. The project was only possible with this interaction between the university and the school, so that the implementation of the SI or RP occurred in real schools and with the participation of Physics teachers as partners. All the activities occurred remotely.

Sample Selection

In general, in pre-service Physics teacher training courses, there are many dropouts and few finish the course. The supervised internship discipline is allocated at the end of the course and the participants of the RP need to be in the second half of the course to be able to participate in that program. In this research there were all the 20 enrolled students in the SI disciplines who were in teaching activities and 24 students who were involved in RP activities.

All 44 pre-service teachers participating in the research carried out Physics teaching activities in public basic education schools in Teresina, under the supervision of the Physics teachers of the school, in the role of supervising teachers (for the 20 SI students) or preceptors (for the 24 RP students). Both groups were guided by the supervising professor, the author of this text. There were 3 schools that had RP students inserted and 8 schools in which the interns were inserted. The pre-service teachers were asked if they authorize the use of their reports and speeches as a data source for a research and they authorized the use for this.

Instruments and Procedures

The research started through conversations with the supervising teachers and preceptors, in which they reported to the pre-service Physics teachers how the teaching was occurring. Based on this information and after contacting the school's classes, as observers, the pre-service teachers were able to propose new activities to be used in their classes. The verification of the results of these activities took place through conversation circles and / or reports.

The data produced for the writing of this article was obtained through the oral reports of the pre-service teachers and / or the supervising professors and preceptors, which were recorded in a field diary, and through the reading of the reports produced by the pre-service teachers of the activities of the SI and the RP, too.

https://doi.org/10.33225/BalticSTE/2021.152

Data Analysis

Considering these described materials, the corpus analysis was performed, using Bardin's content analysis (2016). The data analysis process itself involves several steps to give meaning to the collected data, which are organized by Bardin in three phases: 1) pre-analysis, when the material is organized with the aim of making it operational; 2) exploration of the material, when the definition of categories and identification of the registration and context units in the documents occurs; and 3) treatment of results, inference and interpretation, when condensation and highlighting of information for analysis occurs, generating moments of intuition, reflective and critical analysis.

Research Results

Based on the responses of the in-service teachers, the preceptors or supervising teachers, activities were proposed to be carried out by residents and interns. It was verified in the three schools that functioned as RP nucleus the classes were taking place through Google Meet, in one school that received trainees the teaching was hybrid (face-to-face and remote, simultaneously, and alternating students), 2 used Google Meet and 5 was working via WhatsApp.

The students at the schools where the pre-service teachers acted were poor and a large part of them did not have access to quality internet or access by computers but used mobile data on smartphones. Because of this, most schools operated via WhatsApp, so that students could follow the activities.

Based on these findings, the proposed activities would be carried out by interns and/or residents and the suggestions were categorized according to the type of resource or activity listed. The categories that emerged after the analysis of the field diary and the reports produced by the interns and residents were: Digital Platforms; Simulators - To Develop; Simulators - To Use; Gamification; and Others.

In the Digital Platforms category, platforms that were being used in schools that had classes via lives (the 3 of the RP and 2 with interns) were mentioned and used these platforms to transmit the classes live. The following platforms were listed: RNP, Zoom and Google Meet. These three platforms were made available for free to use. RNP is a platform developed by the Brazilian government and all students and professors at federal universities who have corporate e-mails can open rooms and use them. This platform was used by only one resident, who opened the room and used it in the classes she taught. The other residents and interns used the platforms with rooms opened by the in-service teachers.

Another category that emerged after analyzing the research corpus was Simulators - To Develop, in which Python, Scratch and Tracker were cited. These simulators are programmed by their users, differently from those will be commented on in the next category. They were only used in classes which occurred with lives through digital platforms. These simulators were used only in 2 schools, with Python and Tracker being used in one of them and Scratch in the other. Both schools were nuclei of the RP.

In the 1st school, the one that used Python and Tracker, the use of these simulators was proposed by residents and in the 2nd school it was the tutor who used it and demonstrated to residents how to do it (this teacher finished his master's degree in Physics teaching, in which he used this resource). This fact was curious because it demonstrated the two-way street that occurs when the school inserts pre-service teachers in its activities: both the pre-service, in this case, the resident, and the in-service teacher, the preceptor, learn during the interaction.

Simulators - To Use were verified in the reports of both residents and interns and these resources were used both in classes that took place via lives and in those that took place via WhatsApp. The following simulators were mentioned: Ludoteca, Física in Mãos and PhET. These simulators are available ready for use, requiring only the insertion of numerical values or adjustments such as intensity, angulation, etc., according to the theme that was addressed in each one. They were used as an alternative to replace the experimental activity and demonstrated during the lives or proposed as complementary activities for students who had classes via WhatsApp.

Gamification proposal was also used in classes which took place via lives and those took place via WhatsApp. As in the Simulators - To Develop category, activities in this category were proposed by both pre-service and in-service teachers. In two of RP schools, the preceptors suggested using this approach and explained to residents how these should occur. In two other schools, but which had interns, the interns who suggested gamified activities. In these two schools, activities took place via WhatsApp.

Among the tools used in the gamification process can be highlighted: Google Forms, kahoot, quizizz, quizlet and mentimeter. Google forms, kahoot, quizizz and quizlet were used to ask questions for teams, with kahoot, quizizz and quizlet showing the team that responded most quickly, being indicated for synchronous activities and Google Forms could also be used in asynchronous activities, in proposals such as, for example, gymkhanas. Mentimeter was used more as a graphic element, indicating the most frequent responses, assisting the teacher in the diagnosis of the class.

Others category encompassed the resources cited by the interns who were working in schools where classes were taught via WhatsApp and which could not be included in the previous categories. The following were mentioned: Youtube, social networks (instagram, TikTok and Facebook) and memes. As students using WhatsApp mostly used mobile data, the resources used by pre-service teachers had to consume the least amount of these, so that students could follow the other classes, too.

Discussion

Results presented above demonstrate some possibilities to conduct remote teaching. The five categories listed (Digital Platforms; Simulators - To Develop; Simulators - To Use; Gamification; and Others). The activities of Supervised Training and Pedagogical Residence occurred in schools where the students are poor and a large part of them did not have access to quality internet or access by computers but used mobile data on smartphones. The most classes take place via whatsapp.

As there was no concern with teaching for the use of platforms in classes in a period before the pandemic, the pre-service teachers, although they already had remote classes at the university, learned to use the platforms with use in schools. Thus, it was clear that part of education professionals was not prepared to take on remote learning, as the vast majority did not know how to use digital platforms or did not have the knowledge to handle them, due to the non-mandatory use in the classroom (Ribeiro Junior et al., 2020).

https://doi.org/10.33225/BalticSTE/2021.152

It was commented by all pre-service teachers who used these tools that school students did not turn on their cameras and their active participation was limited to about 2 or 3 per class. A fact that deserves to be highlighted is the supervising teachers and the preceptors commented that the students who participated in the remote classes were the same ones who were active in the face-to-face classes. The same was true for classes via WhatsApp.

In the state of Piauí, according to a survey carried out by the Education Department of the State of Piauí - SEDUC/PI (Piauí, 2020a), 88.82% of students enrolled in this public network are having access to remote activities virtually or through printed material. Among these students, access is distributed in different ways. As shown in Table 1, the teaching contact ranges from WhatsApp groups, instrumental platforms for organizing the content of classes (Google Classroom) and even through other means such as, for example, phone calls, email, etc. 11.18% of public-school students in Piauí continued without access to classes at the time of publication of the report (12/07/2020).

Table 1
Options for Remote Learning Access in the Public Network of Piauí

Contact source	WhatsApp groups	Printed Material	Google Class-room	Others	Without access
Percentage (%)	42.40	24.49	12.52	9.41	11.18

Source: (Piauí, 2020a)

However, even teaching via Whatsapp was harmed because, according to a complaint by Souza (2021), in a May 2021 report, many students are still without internet or cell phone/tablet to carry out the activities after more than a year of the pandemic. This fact made remote teaching even more difficult and forced pre-service teachers to think of new proposals for this teaching.

One of these proposals was by use of simulators. It was verifying two different groups of them: Simulators – to Develop and Simulators – to Use. The first group is more laborious to use because it needs programming. Tracker proved to be the simplest of the three (Python and Scratch were the others in this category), because a recorded video is inserted and some data is described so that the movement can be described and quantified (this simulator can be used only in Mechanics, for it serves to describe the movements). Python is widely used in mechanics, but it can be worked in other areas of Physics, too, such as in electromagnetism (Cristiano et al., 2019) and Scratch can be used for other areas of physics, too, and for production games and other purposes. The students really liked the use of these simulators, especially the Tracker, because videos recorded by the residents were used, showing themselves to be an instrument that brings Physics closer to the students' reality, as commented by Sung, Ma, Choi and Hong (2019).

Both Simulators – to Develop and Simulators – to Use were used as an alternative to replace the experimental activity and demonstrated during the lives or proposed as complementary activities for students who had classes via WhatsApp. Very widespread in the teaching of Physics (Neri, Noguez et al., 2018), simulators have been used by

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supervising teachers and preceptors since before the pandemic and are used mainly as evidence of theory taught in previous classes.

Gamification proposal was also used in classes which took place via lives and those took place via WhatsApp. Gamification uses, outside the context of games, elements of its design to retain the user's attention, motivate and increase activity (Deterding et al., 2011). Among the elements of games that are used are: clear rules, objectives, rewards, inclusion of error in the process, immediate feedback, intrinsic motivation, abstraction of reality, narrative, competition, levels, cooperation, conflict, voluntariness, etc. (Fardo, 2013). The gamified activities were other way used to encourage students to interact more and motivate them, since students have been quite unmotivated in remote activities (Barbosa, 2020). These activities occurred at two schools where the classes took place via WhatsApp.

The last category, Others, included social networks and memes. The social networks cited by pre-service teachers were: Youtube, instagram, TikTok and Facebook. It was found that students accessed social networks with great frequency, being therefore easy for students to see. Another factor led the trainees to propose these resources was the fact that access to many social networks and Youtube are outside the consumption of the students' internet franchise, which they can access without running the risk of ending it.

Most of the time the pre-service teachers forwarded the links to videos or memes before classes, in order to generate curiosity in the students. Some of them questioned the videos and/or memes in class, but even so, feedback was not as expressive, although greater than without the use of these resources. Memes were funny, according to student comments, allowing pre-service teachers to comment in more depth on the phenomenon addressed, as commented by Baysac (2017).

It is also interesting that different approaches have been proposed for use on WhatsApp. The standard form used by in-service teachers was to send activities before class and, at a specified time, in-service teacher was online to answer questions and normally no students showed up for this purpose. Then, a pre-service suggested that along with the materials sent (slides and text in pdf) a brief explanation, typed in WhatsApp itself was sent. Another intern likewise wanted to send an explanation of the content, but used the format of podcast, with short audio recording on WhatsApp itself and said the students' understanding improved a lot, since they were too lazy to read and had no initiative to question.

Since, according to a survey carried out in January 2021, about 4 million students dropped out of school as a result of the pandemic, with the dropout rate being higher among people from the poorest social strata, such as in classes D and E, in which the dropout is 10.6%, while among class A people it is 6.9% (CNN, 2021). Although it is not possible to quantify it, what it was seen by the investigated schools is this number is much higher, in the range of 30% of dropout students. So, all proposals mentioned in the five categories mentioned above were made with the aim of making the classes more dynamic and achieving greater interaction with students, as well as helping to reduce school dropout rates.

https://doi.org/10.33225/BalticSTE/2021.152

Conclusions and Implications

The internship period and the Pedagogical Residency proved to be a rich learning period for the pre-service teachers. Even though the activities took place remotely, the pre-service teachers were able to use different resources and methodologies, experiencing relevant experiences for their training as future teachers, inserted in the reality of the current context.

The pre-service teachers, both SI and RP, proposed different activities in relation to those offered by in-service teachers and helped to improve the quality of education offered to students from public schools in Teresina. It was found that remote / hybrid teaching has a wide range of possibilities for teaching action, but learning is needed so that NICTs can be widely used.

The supervised internships and the Pedagogical Residency proved to be important so that future pre-service teachers could experience in-depth the contents learned during initial training, this applied in real teaching situations. And, in addition, the pre-service teachers, by proposing varied activities during the RP and / or SI, were able to assist in the recycling / training of in-service teachers and in the motivation of their students.

New research must be carried out in order to provide a higher quality in the actions of Pedagogical Residency and supervised internships, as well as to integrate in an increasingly harmonious way the university and the school, collaborating so that a higher level education is offered in schools.

Acknowledgements

The author thanks all pre-service and in-service teachers who assisted in the writing of this article, commenting on their own practice, and clearing up doubts when the reports were not well detailed. The author thanks Capes for the scholarships received to carry out the activities, too.

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Received: *June 10, 2021* Accepted: *August 12, 2021*

Cite as: Rodrigues, M. A. (2021). Challenges for pre-service physics teacher education in a Northeastern Brazilian state in pandemic times. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 152-165). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.152

DEVELOPING STUDENTS' 21ST CENTURY SKILLS IN STEM MENTOR-MENTEE OUTREACH PROGRAMS

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Abstract

STEM education has increasingly drawn attention internationally in recent years. In Malaysia, efforts to encourage students to take up STEM subjects have risen, but student enrolments in almost every STEM subject area have continued to fall over the last decade. The situation is even more challenging in Sabah, an East Malaysian state where 72 percent of its schools are located in rural areas with basic utilities and limited infrastructures. Therefore, a STEM Mentor-Mentee outreach program through university-school partnership was developed to address the gap in STEM education attainment. The program targeted tenth graders (aged 16 years) from rural secondary schools to help them learn STEM by relating it explicitly to their local environment. STEM activities were guided by the engineering design process while harnessing their 21st century skills. Mentors consisting of in-seervice and pre-service teachers who provided guidance, support and assistance to mentees. Data were captured through mentees' responses to open-ended questions, mentors' field notes, focus group observation and interviews. A total of 732 students, 342 in-service and 99 pre-service teachers were involved in the programs from 2015 to 2019. Findings suggest that the program was able to develop creativity, problem solving, critical thinking and teamwork skills among rural secondary school students.
Keywords: *21st century skills, mentor-mentee, outreach program, rural schools, STEM Education, university-school partnership*

Introduction

STEM (Science, Technology, Engineering, Mathematics) education has been given priority in many countries to produce a young generation that is able to compete in the 21st century. The integration of the disciplines of knowledge consisting of science (Physics, chemistry, and biology) and mathematics with technology and engineering into one field of education is known as STEM Education (Ministry of Science, Technology & Innovation, 2015). In Malaysian Education Development Plan (PPPM) 2013-2025, STEM is mentioned explicitly as a specific initiative to be taken by the Ministry of Education Malaysia (MOE). The initiative is to strengthen STEM education as to produce human capital in the 21st century who have higher order thinking skills, innovative, prudent, independent, technologically literate, able to create, able to solve problems and make decisions (MOE, 2016).

The demand for a STEM driven workforce in Malaysia has become a burgeoning need as the economy has evolved from a production-based economy to a knowledge-based economy. It has been estimated that Malaysia would need 500,000 scientists

https://doi.org/10.33225/BalticSTE/2021.166

and engineers by 2020 to cope with the challenges of the Fourth Industrial Revolution (Academy of Sciences Malaysia, 2015). However, at that point, it had only 70,000 registered engineers. Undeniably the supply of STEM related workforce is highly dependent on new entrants into STEM related program in upper secondary as well as tertiary level. However, report has shown that only a total of 22.5% of students have enrolled in science stream, and technical and vocational secondary school classes in 2017, which is still far from the ideal ratio of 60:40 Science/Technical: Arts Policy set in 1970 (Academy of Sciences Malaysia, 2018).

The challenge of achieving the 60:40 Science/Technical: Arts Policy is even tougher for the vast rural areas of Malaysia due to its limited infrastructure, lack of good schools and small population (Ling et al., 2015). Sabah, an East Malaysian state with a relatively high proportion of students in rural schools is facing a more challenging situation with respect to its efforts to keep pace with STEM Education. According to the Sabah Economic Development and Investment Authority Blueprint (SDC, 2011), 72% of Sabah's schools were located in rural areas. In terms of infrastructure and basic utilities, most rural primary and secondary schools in Sabah lack supplies of 24-hour electrical connection, access to good teaching and learning resources, computers, and science laboratories. It is apparent that these limited opportunities and facilities have somewhat created a gap in STEM education attainment between rural and urban schools in Sabah and in Malaysia as a whole.

In countries such as Colombia and the United States of America, an outreach program is usually designed to help and encourage disadvantaged students of rural schools to increase their STEM literacy and enthusiasm. These after school STEM outreach programs aim to improve the quality of science education (Laursen et al., 2012), motivate school students to choose STEM subjects in the future, and generate more graduates who have the capacity to pursue science-based careers (Moskal & Skokan, 2011; Office of the Chief Scientist, 2013). While these outreach programs examined the students' STEM literacy and enthusiasm, there is a lack of research examining the program impact on students 21st century skills, thus a gap in the literature that this research will fill.

Brookshire (2014) highlighted the guidance from the right mentor in mentoring can expand students' ideas about the possible careers in STEM fields and trigger a passion for STEM. These observations raised a crucial question: "How would a mentor-mentee outreach program help students in rural secondary schools learn STEM?". Tackling questions like this, particularly in rural settings often requires a more integrated approach to STEM education.

According to Essex (2001), school-college partnerships hold significant promise for renewal and improvement in education (pp. 736). Essex pointed out that successful partnerships allow both the school and the university to work together in an environment in which synergy leads to better decision making, thus having a positive effect on student learning. In this matter, a school-university partnership can help to address the needs of rural schools by providing adequate support and access in the development and delivery of STEM outreach program. Thus, there is a need to adopt an integrated school-university partnership and mentoring approach to produce maximum mutual benefit for all involved in the outreach program, and to seamlessly examine what rural school students would learn during the outreach program. By exposing children to STEM and

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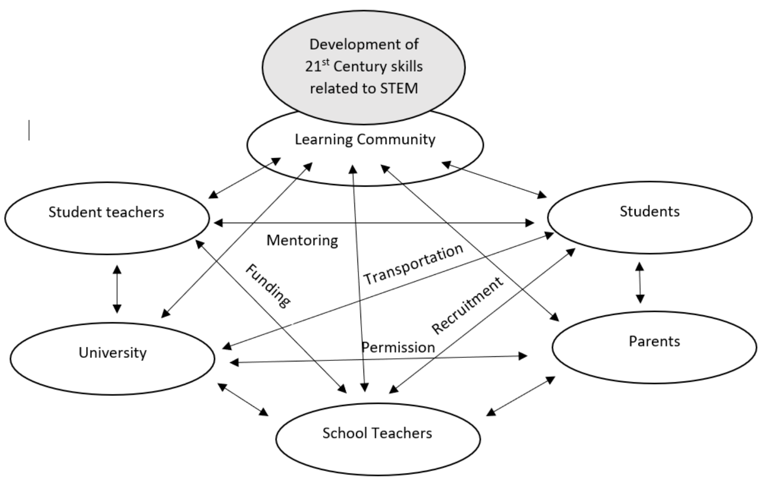
giving them opportunities to explore STEM-related concepts, they will be equipped with 21st century skills such as critical thinking, problem solving, creativity, collaboration, and communication skills as desired by MOE Malaysia (MOE, 2016).

To ensure inclusive and equitable STEM education, a STEM mentor-mentee outreach program through university-school partnership approach has been developed to support disadvantaged and marginalized students in the rural areas. Specifically, this outreach program aims to improve the reach of STEM education in schools geographically distant from the cities of opportunity based on the concept of contextualization and collaboration. This enables rural students to understand STEM by relating it explicitly to their local environment and to increase their 21st Century skills. As such, the objective of STEM mentor-mentee outreach program is to find out if mentor-mentee outreach program would help students in rural secondary schools develop their 21st century skills related to STEM.

The University-School Partnership Model

Bernay (2020) proposed Transformational Learning Community (TLC) model as one form of school–university partnership to address the challenges of the future. The TLC model suggests that the current teaching practices in schools and in universities should be extended into the real world. The purpose is to generate thinking and knowledge creation for children or student teachers to thrive in today’s world. Bernay continued to address that learning communities should focus on change; to reinvent schools for transformational learning for children, student teachers, teachers, university lecturers and the wider community. Recognizing the advantages of TLC model to cater to the needs and challenges faced by students in the rural areas, TLC model was adapted in realizing the school–university partnership in the outreach mentor-mentee program. Figure 1 illustrates the range of relationships and resulting benefits in the adapted TLC model.

Figure 1
Transformational Learning Community Model (adapted from Bernay, 2020)



https://doi.org/10.33225/BalticSTE/2021.166

In order to work in an authentic partnership with rural schools in Sabah, a community of practice was created to draw on the expertise and experience of university science lecturers and student teachers involving in-service and pre-service teachers and co-constructing outreach programs with school teachers, principals and parents. In other words, university Malaysia Sabah (UMS), UMS science lecturer, UMS in-service and pre-service teachers, heads of school science department, school principals and parents were working as a team to carry out the program. The parents granted permission to allow their children to participate during the weekend (Saturday). School principals and heads of science department collaborated to provide the school hall and PA system to be used for the activities. The university provided free bus service to transport the mentors and materials to the schools which are located 16-180 kilometers from Kota Kinabalu, Sabah.

The resources used for running the program were funded by schools and university. The Centre for External Education of the university allocated RM50 to each of its master students to run the program outside the classroom, which was used to support the cost needed to buy materials and equipment. The in-service teachers also sought sponsorship from the local community such as businessmen to support the cost for food and drink for mentees and mentors. The in-service teachers also play their roles in borrowing science apparatus from their school laboratory such as crocodile-clips, hot gun, and glue gun sticks to support the activities. Recycled materials such as plastic bottles, empty boxes, newspapers, and egg trays were collected by mentors which were used as main resources for the activities. Some tools and materials such as scissors, rulers and cutters could be re-used in the followed-up program. Administrative costs were extremely low as free messaging platform such as telegram and WhatsApp were used to ease the communication among people one month prior to the start of the program.

Engineering Design Process Model

The Massachusetts Department of Education (2006, p. 84) proposed eight steps of engineering design process which provide a guide for teachers and curriculum coordinators regarding learning, teaching, and assessment in science and technology/ engineering specific content from Pre-Kindergarten to Grades 6-8 and throughout high school. Those eight steps of engineering design process include identifying the need or problem, research the need or problem, develop possible solution(s), select the best possible solution(s), construct a prototype, test and evaluate the solution(s), communicate the solution(s), and redesign.

Many researchers claim that STEM curricula can be integrated in an engineering design process to provide a mechanism through which students learn relevant STEM content (Hmelo et al., 2000; Mehalik et al., 2008; Schunn, 2009). This mechanism encourages students to make connections, helps connect design failure or next steps to real world engineering and technology (Lottero-Perdue, 2015). Students learn important scientific concepts and their application in engineering and technology, as well as their relationship and application in daily life or real-world context. Students could look for connections by engaging with activities or material in 'real-world' contexts to establish relevance. This approach can attract students' interest in science lessons and provide them with a deep understanding of concepts and meaningful learning.

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Hynes et al. (2011) noted that engineering design process that focus on solutions and construction of prototypes impel students to encounter the process of creative and critical thinking as well as problem solving skills. Hence, engineering design process would offer a route as an instructional framework for fostering 21st century skills among rural secondary school students. According to Mentzer, Huffman and Thayer (2014), engineering design problems embedded in the context of an engineering design process in practice tend to be structurally open-ended and highly complex. Engineering design problems are also designed to be ill-defined. King and Kitchener (1994) characterized ill-defined problems as problems that have no clear-cut right answer and require the integration of many skills and abilities. Solving ill-defined problems requires judgment, planning, the use of strategies, and the implementation of previously learned skill repertoires.

Science teachers in previous program noted several potential challenges while implementing a STEM-project-based learning approach in their rural school classrooms (Siew et al., 2015). These included inadequate materials, limited facilities, and limited allocation of classroom time. Accordingly, the engineering design process employed in this program removed the 'redesign' step proposed by the Massachusetts Department of Education (2006, p. 84). This modification was made to ensure that students could produce workable prototypes that made best use of the materials and time provided in the program.

The Design and Development of STEM Mentor-Mentee Outreach Program

The STEM mentor-mentee outreach program was designed and developed by a science lecturer as program coordinator and assisted by in-service and pre-service teachers. The pre-service teachers were second and third-year undergraduates aged between 22 and 23, training in Physics and Mathematics Education and had no teaching experience in schools. In-service teachers were qualified teachers with degrees in Science and Social Science Education who were undertaking Master course at the time.

Mentor-Mentee. Prior to the program, the faculty recruited mentors among in-service and pre-service teachers, each of whom signs up voluntarily in exchange for experience and competence. Mentors have attended a one-day training course in peer mentoring arranged by the program coordinator. Mentors were trained to conduct facilitation and assessment to their mentees. The mentors were empowered to carry out their role as evaluators and facilitators during the program. After completion of their mentor role, mentors are awarded a Certificate of Contribution by the faculty dean.

The Grade Ten Science Stream students from the secondary rural schools were chosen as the mentees of the program. Mentees received guidance, support and assistance from mentors in finding solutions to problems, using materials, sketching, and building prototypes.

Ill-defined Problem and STEM Activities. The ill-defined problem was introduced to students within the context of their daily life. Students were engaged to connect their daily life experience to solving ill-defined problems. Students would be also asked to consider the constraints of the materials and time, think about what they already know, design, plan, construct, test and evaluate a physical prototype of their design.

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STEM activities were guided by the adapted engineering design process (EDP). The EDP provides a flexible process that takes mentees from identifying a problem, designing a solution to developing, creating, testing and evaluating a prototype to solve daily life problems in their environment using inexpensive materials. It allows students to realize that there are many ways to find solutions, as they engage in brainstorming to identify problems and propose solutions. The process of finding the optimal solution based on constraints requires participants to engage in critical thinking, creativity, imagination, collaboration and communication skills, and problem-solving skills.

Different STEM activities were introduced in each school with local context to enhance learning and understanding of the STEM concepts. A total of three STEM activities were introduced in each school, each taking about three hours and 20 minutes. Examples of ill-defined problems embedded in STEM activities are as follows:

1. "Ali saw a bird perched on a tree branch. A question arose in Abu's mind, 'How can it perch for such a long period of time?'

Your task: Create a balancing toy that can stand stably on your fingers like a bird. Each student must produce at least one balancing toy that meets the requirements.

2. "After a year of construction, the Mesilou river bridge that collapsed due to the earthquake has been completed. This news is quite exciting for the villagers who want to cross the Mesilou river. But some are wondering: How much weight can the vehicle support by the bridge? Is it really safe? You and your friends have been given the opportunity to show the villagers that the Mesilou bridge is actually strong enough to support the weight of vehicles crossing it".

Your task: You and your friend are asked to prove it by designing and building a bridge that crosses a river which is one meter wide. The bridge is strong enough to hold at least 3 cans of coca cola.

Higher-Order Thinking (HOT) Questions. Students also needed to answer the Higher-Order Thinking (HOT) questions that stood of questions that were not strictly in their curriculum. In a way, answering HOT questions inspired students to acquire new found competences. Anderson and Krathwohl (2001)'s Taxonomy was used as a guide to develop a blueprint for the HOT questions, which belonged to the Analysis and Evaluation category of the cognitive domain. Some samples of HOT questions used were: 'In your opinion, if buildings were constructed identical to this prototype, is it safe to be inhabited? If yes/no, please explain why?'(Evaluation); 'How can your prototype be modified in order to improve its results in the future?'(Analysis); and 'Explain why there is a difference of the submarines' speeds between the two bottles? (Analysis)'. The HOT questions were specially designed to evaluate students' critical thinking skills in connecting STEM activities with their daily life.

Scoring Rubrics. Scoring rubrics were developed for mentors to evaluate the prototypes produced by the group during the presentation and testing. Aspects assessed were product functionality, sketches, group collaboration, and understanding and application of scientific concepts. Scoring rubrics were constructed based on analytical scoring. The quality of student responses and products was assessed from "Poor" (lowest level) to "Very Good" (highest level).

Research Methodology

Research Design

A single group with intervening STEM mentor-mentee outreach program design was used in this research. This was a case study whereby qualitative approach was employed to gain an in-depth knowledge of the participants' 21st century learning experiences in implementing STEM mentor-mentee outreach program. The Grade Ten Science Stream students (aged 16 years) from the secondary rural schools were chosen as the participants of the research.

Research Instrument

Research instruments included mentors' field notes and mentees' responses to open-ended questions; focus group observation and interviews.

Field Notes. Mentors wrote their field notes based on the observation made during the STEM activities, and the semi-structured focus group interviews with mentees. Focus group observations were collected using an observation form adopted from scoring guides developed by Wang et al. (2015). The quality of the students' responses was ranked from "0" (Level 0: the lowest level) to "3" (Level 3: the highest level). The interview questions were open-ended and the students were encouraged to draw explicitly from their learning experiences of working on the STEM activities. Each focus group interview was conducted in groups consisting of 4-5 mentees after the completion of each STEM activity.

Open-ended Question. A paper-based open question was administered at the end of the program. in view of obtaining written feedback from mentees Students were asked to reflect on their learning experiences following their participation in the STEM mentor-mentee program by responding to the question: 'Something new I have learned today was…" The open-ended questions offered the mentees an opportunity to clarify, and to fill gaps of missing information not captured by the focus group observations and interviews with mentees.

The Implementation of STEM Mentor-Mentee Program

The program was implemented in 16 rural secondary schools in the districts of Tenom, Tambunan, Ranau, Tuaran, Kota Marudu, Kudat, Penampang, Putatan, Telipok, Sipitang and Kiulu throughout 2015 - 2019. Throughout the five-year program, a total of 732 students, 342 in-service and 99 pre-service teachers were involved in STEM mentor-mentee outreach programs.

In these programs, mentees in group of four or five collaborated to solve an ill-defined problem utilizing the engineering design process. Mentees worked collaboratively to design, build, and test prototypes of their inventions according to the criteria set in an ill-defined problem. Mentees could respond to the ill-defined problems

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in many ways with many different solutions. Mentees also would have opportunities to make use of their STEM knowledge and skills to solve the problem and choose their favorite strategies to obtain their unique solutions. Aspects of science and mathematical concepts and communication skills were also emphasized and evaluated during the presentation of prototypes by group members to their peers and mentors.

Group mentoring involves one or two adult mentors forming a relationship with mentees. The mentors play the role of facilitator and makes a commitment to interact with the mentees over the period of one-day program. The interaction is guided by activity worksheets, which allow time for two ways discussion of the STEM activities.

Data Analysis

Mentors' field notes and mentees' responses to open-ended questions were analyzed using thematic analysis. Thematic analysis is a form of a pattern recognition technique by searching through the data for emerging themes.

Research Results

Solving Daily Life Problems using Scientific Knowledge

Almost every mentee (98%) noted that they benefitted from the STEM activities as they were exposed to real-life situations where scientific knowledge was applied for solving daily life problems. More importantly, STEM activities succeeded in providing a platform for them to apply scientific knowledge in solving problems. Among the scientific concepts the mentees noted were related to water and air pressure, equilibrium of force, base area, balanced force, surface tension, stability, water density and the buoyancy force in a submarine. Mentors from one group confirmed that interviews with mentees revealed that mentees found the need to apply the concept of impulse in order to create an innovation that help to absorb the impact of an egg being dropped from a high place.

Answering Higher Order Thinking (HOT) Questions using Scientific Knowledge

A significant number of mentors (88%) observed that a profound comprehension of scientific knowledge helped participants answer high level questions and to be creative in reapplying knowledge learnt in the designing and producing of prototypes. Mentors observed that HOT questions provide mentees an opportunity to think critically about the answers and make connections with scientific concepts they have learnt in class.

Connecting STEM Activities with Daily Lives and Scientific Concepts Learned

A large percentage (93%) of the mentors noted in their field notes that participants learned how to make connection of the STEM activities with their daily life phenomenon. For example, mentors observed that mentees could relate how ships or boats function and why they could float on the surface of water by making comparisons with their own made boat models. Another example is when answering the HOT questions, mentees could affiliate the floating needle and paper clip activity with the water strider bug,

https://doi.org/10.33225/BalticSTE/2021.166

a floating log, water lilies, floating ants, and others. Mentors supported these claims by noting that "*Scientific knowledge is not only for answering exam papers but also useful in helping students create connections and explain situations faced in their daily lives. In this case, it is observed that students applied scientific concepts they learned during Physics lessons in problems given to them. Students not only applied the science principles and laws they learnt but also used them in practical forms*".

HOT Questions sparked Critical Thinking

A large percentage (93%) of the mentees expressed through the open questions that they were challenged to think critically when answering the HOT questions in the STEM program. The mentees felt that the HOT questions were difficult, but they tried their best to answer and associate them with their prior knowledge.

According to mentors, mentees were capable of giving rational answers to the HOT questions. For example, one of the group members gave an excellent answer and showed that he/she understood the concept and was able to give a suggestion to improve the existing prototype if given the chance to design it with the aid of extra materials. The sharing of answers added knowledge collectively to the group besides increasing their critical thinking skills. According to mentors, the STEM activities tested and challenged mentees to think outside the box using higher order thinking skills.

Designing and Building Something New and Practical

A large percentage (96%) of the mentees expressed in the open questions that STEM activities gave them an opportunity to create many new, interesting and practical science products using everyday materials. They stated that the balloon powered car made from plastic bottles was a new experience for them. They were fascinated with finding new ways to make a highly powered car moved by air using ever ready materials such as glue, bottles, pencils, and others. Another activity was making a boat. The mentees said they realized that play dough can float when shaped into a boat. Others noted that finding gravity center through making the balancing toys was a new activity. Meanwhile, a few mentees commented that they discovered new ways of floating the needles and paper clips.

When participants were asked why they were excited with the STEM activity, they answered that: "*because we got the chance to design and build a new model which we only see in textbooks*". Other than that, students showed interest in STEM activity because they could become 'designers' of their own boat in the future. Mentors observed that the mentees could design egg protection tools and that every group member worked together the whole time by contributing ideas and carrying out the projects as they had planned. Thus, according to mentors, STEM activity seems to provide a very good start to stimulate the interest of mentees in learning STEM.

Thinking Creatively through Combination of Ideas

A considerably large percentage (78%) of the mentors noted in their field notes that they were amazed when mentees exhibited creativity above anticipations. Group works enhance mentees' ability to produce all kinds of products using limited materials

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as a result of the combination of ideas by group members. This can be seen during the construction of the bridge using the newspaper. Many new ideas and views were brought up during brainstorming within the group. With a combination of ideas from group members, they were finally able to build a paper bridge that could be crossed by 3 cans of drinks. Thus, mentors noted that teachers need to acknowledge students' potential and use the right tools and mentorship to enhance their hidden potentials.

Ill-Defined Problems inspired Creativity and Thinking

A significant number of mentors (93%) reported that mentees faced complexities posed by ill-defined problems in the program. These ill-defined problems demanded from them effective response to the challenging tasks which in turn inspired creativity and thinking. For example, the mentees' creativity levels were tested while creating a bottle car that was powered by a balloon. Participants had to figure out ways to move a car by using only air within a balloon, and to think of a method of reducing the car's weight and decrease its tire resistance

Sketching, Designing and Constructing Models fostered Creative Thinking and Problem-Solving Skills

A considerably large percentage (88%) of the mentees expressed opinions that STEM activity encouraged creative thinking, and also problem-solving skills. This was because each activity needed them to sketch and design models according to the creativity of each group. Mentees noted that they had to think of a way to design models that worked and at the same time possessed creative elements. For example, the activity of 'balancing toys' had successfully induced creativity and imagination within mentees as almost every one of them were able to build a balancing toy with different designs. Unexpectedly, mentees in one group were able to create nine balancing toys with different designs. Furthermore, this activity also enhanced mentees' thinking skills. Mentees gained ideas on how to create their own toy design. Hence, it encouraged them to think more profoundly. This was supported by observations made by mentors who noted that: *"Besides creating one 'balancing toy', students can think of ways to merge a few 'balancing toys' in a stable condition"*.

Instilled Thinking through Teamwork

A significant number of mentors (93%) observed that mentees not only came up with some thoughtful ideas but also showed a spirit of teamwork during the STEM activities. Mentors described mutual understanding and cooperation, boosted the confidence of each mentee to do his/her best work in order to construct a workable prototype. Mentees made attempts to cooperate as a group to solve the problems and brainstorming within the group helped mentees to increase their critical and creative thinking. This was proven when a group of five was able to create nine balancing toys with different designs. In another group, group members divided up some tasks such as rolling up a newspaper and stitching together some newspapers in order to produce a paper bridge which in their opinion was a very difficult and challenging activity.

https://doi.org/10.33225/BalticSTE/2021.166

Solving Problems with a Determined Effort

A large percentage (92%) of the mentors reported that STEM activities challenged the mentees to think of many ideas and make many attempts without giving up. Mentees tested their prototypes through many attempts, improved or modified their original idea through the process of trial-and-error. For example, mentees made modifications to the boat several times so that the boat they built could hold up to 26 marbles. They proved their seriousness in solving the problem despite having to repeatedly test the boat's ability to accommodate large quantities of marbles.

Discussion

The STEM Mentor-Mentee outreach program executed a new idea which addresses a specific challenge of revitalizing STEM movement in rural secondary schools and adds value to rural school students, teachers, and the University. The program used university-school partnership model to reach out to rural schools to improve the 21st century skills and make it more relevant to local context.

Evidence from mentees suggests that the program enabled them to apply STEM knowledge in solving daily life problems, designing and producing daily life products, and answering HOT questions. Mentees were also able to connect the STEM activities with daily lives and scientific concepts learned in the classroom, and to create new products using everyday materials. These findings make clear that the execution of the engineering design process in STEM mentor-mentee outreach program can help mentees in relating and applying STEM knowledge to their daily life problems and contexts. Researchers are in agreement that engineering design process provides a mechanism through which mentees learn to make connections by engaging in ‘real-world’ problems and contexts (Lottero-Perdue, 2015; Neo, Neo & Tan, 2012).

The STEM mentor-mentee outreach program not only allowed mentees to gain and integrate STEM knowledge but also provided an avenue to boost their creativity, critical thinking, problem solving skills and teamwork. Mentees’ creative and critical thinking was sparked through solving HOT questions and ill-defined problems posed in the STEM activities. In addition, as mentees went through the engineering design process such as selecting the best solution in sketching, designing and constructing a prototype have helped them to foster their critical thinking, creative thinking and problem-solving skills. Hence, engineering design process offers a route for mentors to foster 21st century skills among mentees from rural secondary schools. Hynes *et al.* (2011) supported that engineering design process provides students an opportunity to practice critical thinking skills as well as outside-the-box thinking. King and Kitchener (1994) also asserted that exposure to ill-defined problems that mimic those solved by real-world practitioners help students develop problem-solving and critical-thinking skills. This research demonstrates that engineering design process employed in STEM mentor-mentee outreach program allows mentees to focus on solutions to ill-defined problems that could encounter them in the process of creative and critical thinking, and problem-solving skills. The findings of this research suggest that designing ill-defined problem scenarios for the program provide a framework by which mentees can engage in 21st Century skills.

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In this STEM mentor-mentee outreach program, new ideas were generated through the combination of ideas of group members as well as through the trial-and-error method. Mentees as a group respond effectively even with limited materials and time in organizing their thoughts to choose the best possible solution for their prototype using related scientific concepts. Thus, this explains mentees who were actively engaged in collaborative activities could encourage their critical thinking development if mentors guide their critical thinking processes as addressed by *Snyder and Snyder* (2008). This research highlights the important role of mentors to boost the team spirit during the STEM activities.

Similarly, in the STEM activities, students could respond to the ill-defined problems in many ways with many different solutions. Ill-defined problems engage students to make comprehensive use of their STEM knowledge and skills to solve the problem and choose different strategies to obtain their unique solutions. This is in fact a supportive environment in developing many unique responses through teamwork, in line with Sawyer (2003) who stated that people who are engaged in activities together produce a novel outcome. This research highlights that mentees who were engaged in group work during mentor-mentee outreach program were able to generate more novel solutions to a problem, hence promote their creative thinking.

While the mentees described many positive learning experiences gained in this program, they also pointed out several challenges that test their resilience. The most commonly mentioned challenge was the conducted STEM activities required the use of a wide range of cognitive abilities. Mentees tested their prototypes through many attempts, improved or modified their original idea through the process of trial-and-error. This program makes clear that guidance, support and assistance by mentors would clearly help some mentees to complete the prototypes, and thus adequate mentoring from mentors to trigger students' thinking is a critical matter and should be enforced by mentors.

Conclusions

This research provides support for the need of university-school partnerships in making STEM mentor-mentee outreach program a reality in the long run by offering a meaningful way of developing 21st century skills among rural high school students. This research exhibits that many 21st century skills involving high-level cognitive and transferable skills could be inculcated through one STEM mentor-mentee outreach program: problem solving, critical thinking, creativity, communication skills, and teamwork. These are the soft skills essential to be successful in a STEM career.

This research also supports new research examining the potential implementation of STEM outreach programs and university-school partnership in elementary rural schools. Life skills such as entrepreneurial thinking skills can be introduced in the program to examine whether the rural school children could apply these skills in addressing "localized" problems and issues and turning problems into marketable product. Thus, the idea of STEM mentor-mentee outreach program and its activities can be adjusted and fine-tuned by any educators to be researched to new group of students based on the local context**.**

https://doi.org/10.33225/BalticSTE/2021.166

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Received: *June 15, 2021* Accepted: *August 19, 2021*

Cite as: Siew, N. M. (2021). Developing students' 21st century skills in stem mentor-mentee outreach programs. In. V. Lamanauskas (Ed.), *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)* (pp. 166-179). Scientia Socialis Press. https://doi.org/10.33225/BalticSTE/2021.166

KEYNOTE SPEAKERS

Prof. dr. **Paul Pace**
University of Malta, Malta

Title: THE SUSTAINABLE DEVELOPMENT GOALS: MAKING SCIENCE AND TECHNOLOGY GLOBALLY RELEVANT

Prof Paul Pace has been active in Education for Sustainable Development (ESD) as founder and former director of the Centre for Environmental Education & Research; chairperson of Malta's National Strategy for Education for Sustainable Development; founder of the Malta Association of Environmental Educators; and as a researcher at the Faculty of Education, University of Malta where he is a full time associate professor in ESD and science education.
Appointed Eco-Schools National Co-ordinator for Nature Trust FEE Malta and the GLOBE (Global Learning and Observations to Benefit the Environment) Programme Country Co-ordinator, he is the vice-chairperson of the Interdiocesan Commission for the Environment of the Maltese Archdiocese. He was involved in several local and foreign projects aimed at the development of curriculum material for ESD and science. He works actively with teachers in the implementation of sustainability policies in schools. A former teacher of biology, he was involved in several science examination boards and served on the National Curriculum Framework Review committee and the National Science Strategy committee.

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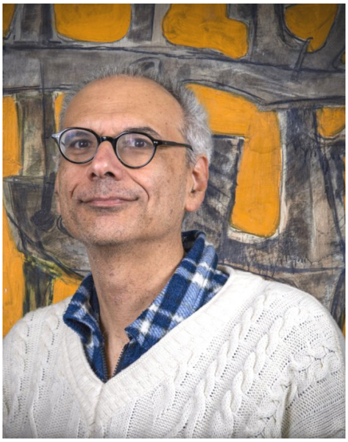

Dr. **Paolo Bussotti**
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Title: A NEW PERSPECTIVE ON MATHEMATICS EDUCATION COMING FROM HISTORY: THE EXAMPLE OF INTEGRAL CALCULUS

Dr Bussotti graduated with first-class honours in History of Science and Technology from the Faculty of Humanities (degree course in History) of University of Pisa on 25th November, 1991. In July 1996 he received a Ph.D. in Historical Sciences at the University of San Marino, with a thesis on the foundations of mathematics, wherein he analysed four authors in particular, namely Bolzano, Cantor, Frege and Husserl. In 2005 he was appointed with a Humboldt fellowship at the LMU, Munich.
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Title: COGNITIVE PROCESSES IN THE THEORY OF PHYSICS EDUCATION

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Prof. Dr. **Malgorzata Nodzynska**
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Title: CHEMICAL VS. NATURAL: COMMON MISCONCEPTIONS

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Lamanauskas, V. (Ed.) (2021). *Science and technology education: Developing a global perspective. Proceedings of the 4th International Baltic Symposium on Science and Technology Education (BalticSTE2021)*. Scientia Socialis Press.
ISBN 978-609-95513-7-1 /Print/, ISBN 978-609-95513-8-8 /Online/

Compiler	Vincentas Lamanauskas
Designer & Paste-up artist	Loreta Šimutytė-Balčiūnienė
English language proofreader	Ilona Ratkevičienė

15 September 2021. Publishing in Quires 11,5. Edition 90.

Publisher Scientia Socialis, Ltd.
29 K. Donelaičio Street,
LT-78115 Šiauliai, Lithuania
E-mail: scientia@scientiasocialis.lt
Website: http://www.scientiasocialis.lt/

Printing Joint-stock company „Šiaulių spaustuvė"
9A P. Lukšio Street
LT-76207 Šiauliai, Lithuania
Phone: +370 41 500 333.
Fax: +370 41 500 336
E-mail: info@dailu.lt

ISBN 978-609-95513-7-1 /Print/,
ISBN 978-609-95513-8-8 /Online/