

Article

Designing a Tool for an Innovative, Interdisciplinary Learning Process Based on a Comprehensive Understanding of Sourcing: A Case Study

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Abstract: The paper presents a case study describing the process of creating and validating the benefits of two Innovative Learning Tools (ILTs) aimed at more effective knowledge acquisition in the interdisciplinary field of earth resource extraction with links to the status of renewable energy. The philosophy behind the original designs and the design of the two tools, the way they are used, and the results of their application in the educational process are presented in a framework. The opinions and attitudes of both students and educators towards the tools were surveyed, and some research questions related to this form of knowledge acquisition were validated. The presented results show the students' interest in the educational form as well as the attractive content that goes beyond conventional educational subjects, with its connections.

Keywords: education; RES; Innovative Learning Tools



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1. Introduction

The issues of the impacts of anthropogenic climate change on human society appear to be one of the most pressing issues of our time, reflected in political, economic, social, and personal terms [1–6]. Addressing the issues is the subject of major events such as summits (Climate Adaptation Summit) [7], meetings of international organizations (Glasgow Climate Change Conference) [8], scientific conferences (2nd International Conference on Environmental Science and Applications (ICESA'21)) [9], and so on.

In addressing, or rather finding solutions to, the identified problems, the massive take-up of Renewable Energy Sources (RES) is often seen as a solution to the problem. While in 2010 the world's energy production from RES was at 761.2 TWh, in 2020 it was already 3147 TWh [10]. In 2021, 70% of the 530 billion USD spent on energy production should be invested in renewable energy sources [11]. There are also various youth demonstrations taking place around the world for sustainable development and climate change mitigation measures, as well as for the reduction of emissions and decarbonizations of human activities [12,13].

However, aspects of the problem remain in the background, which are related to the overall shape and size of the current human society with a population of 7.9 billion [14] built on the intensive use of natural resources (raw materials, water, land, forests), the global economy, regional differentiation, transport, etc. [15] Understanding the material base and the energy background of these aspects is essential for the creation of a feasible framework of measures that can somehow lead to at least partial elimination of the problems or to the creation of more effective tools for solving some of the current problems [16]. For this reason, it is important to understand the needs and extent of the application of renewable energy sources in practice and this is not possible without a consistent and comprehensive understanding of the source of raw materials and energy in their historical and current form in the context of the global economy and society [17–19]. This concerns the people

working in the industries concerned (mining, energy, transport, processing industry, waste management, environmental protection, etc.), politicians, people creating a legislative framework for the implementation of new solutions, access to and technologies using portfolio RES, but also the common public, which is the bearer of certain ideas due to public opinions or awareness, which create the basis for potentially global applicable and effective changes in socio-economic activities. An important role in this is played by the building of awareness and knowledge among the next generation, which takes place in the school environment through the educational process [20]. Additionally, on the basis of many years of teaching experience in the field of higher technical education, we can state that young people often take very courageous and ambitious attitudes to problems, which, however, are often not based on sufficient knowledge of the issues or are not based on an adequate knowledge base. It is in this area that attitudes to the issue of securing the energy and raw material base of human society today and in the future also fall. Education on RES as well as on earth resource extraction in general is currently carried out conventionally and is tied to isolated topics within individual scientific disciplines. Conventional educational forms often do not lead to the desired results, if only because of the low degree of attractiveness, which is illustrative in relation to the empirically acquired subjective perception of reality. For this reason, various other educational forms are emerging, in the creation of which their authors try to include elements with added attractive and motivational value, as well as integrating inter- and multi-disciplinary approaches [21–23].

In the FMEPCG (Faculty of Mining, Ecology, Process Control and Geotechnologies) environment, we create many interesting activities in this direction, which have been subject to a certain natural evolution, conditioned both by the feedback and achievements of previous work, triggered by external factors. The key factor for faster development in the last years was the pandemic situation related to COVID-19, and that was an imaginary wheel, which led us into faster changes in the teaching process.

The present paper presents a view of the process of creating an innovative educational form and its content and the results achieved, as a kind of case study that can be an important source of data, information, and experience for other analogous activities.

The process of developing those tools for this type of education includes didactic, creative/innovative, and professional knowledge in the disciplines and much information, which are included in a broader context point of view.

Looking at the learning process itself, the theoretical aspects of the mechanism have been comprehensively elaborated and published in many publications [24]. According to Vester [25], the types of learning are based on five types of perception, according to which channel is dominant in the reception of information, and, thus, we distinguish: auditory type, visual type, learning by reading, tactile type, and combined type. In this context, for example, the source [26] cites Roy's (1995) [27] data on what and how we remember, which accounts for 10% of what we hear, 15% of what we see, 20% of what we simultaneously see and hear, 40% of what we discuss, 80% of what we directly experience or do, and 90% of what we try to teach others. The motivational aspect of curiosity-play may play a very important role here, as several studies suggest. According to the source [28], maintaining the "curious spirit of the young child" may be one of the keys to successful learning. Here, there is a possible connection between all three domains of learning according to Bloom [29], namely, the cognitive domain (learning to recall certain facts, to think, make decisions, and to get better at it, to acquire a certain skill), the psychomotor domain (learning practical skills), and the affective domain (to develop values, feelings, and beliefs).

There are several studies similar to the one which is presented in this article that have investigated the incorporation of innovative elements into the teaching process and their impact on students' ability to retain information for longer periods of time. Under innovations or innovative educational toolkits, we understand the implementation of materials, games, group projects, and toolkits that provide information and knowledge to students in a form other than convectional. There are more interesting ways to show very essential information to people and, as was mentioned before, this area is more attractive

for Z generation. This generation is more educated in the use of new technology and the app that was created, giving them opportunity to be in familiar fields and giving them more perspective and an interesting education. Kvam investigated the effect of Active Learning Methods on student retention in Engineering statistics, and his findings suggest that active learning can help increase retention rates for average or below average performing students [30]. Zakaria found that cooperative learning improved math scores by nearly 11%, and 13% of students had a positive attitude towards math after this style of learning [31]. Risnita and Bashori compared conventional and contextual learning, finding that the contextual learning group outperformed the conventional learning group by 20.9% [32]. According to Ponomarenko, innovative teaching at selected universities is more prevalent in economics majors, less so in engineering majors, which causes students to be underprepared for an interdisciplinary perception of knowledge [33]. The positive effect of innovation in the educational process was also confirmed by Setiawan [34]. The results of Sadeghi's study were that the combined method of education is more satisfying for students, but it is more time consuming and more demanding for the teacher to prepare; moreover, the results of both methods (classical lectures and e-learning) were very similar [35].

In order to develop creative abilities and to link the different cognitive domains in education in the field of earth resource extraction and the use of renewable energies, the Laboratory of Earth Resource Extraction (LERE) was established at FMEPCG in 2012 (Figure 1) [36], which soon brought results not only in stimulating a deeper interest in the unconventional way of rendering reality but also in new application possibilities of this creative environment, producing a number of outputs in the forms of original bachelor and diploma theses, several of which have won leading positions in faculty and international rounds of the Student Scientific Competition and Student Scientific Conference as well as prizes of the Association of Slovak Scientific and Technical Societies. Students quickly understood the potential of such “playful” teaching and showed a real interest in applying their creative abilities during their studies and in their development under appropriate pedagogical guidance.



Figure 1. Laboratory of Earth Resource Extraction, Cube [37].

In 2020, the LERE was expanded with the ECL Engineering Creativity Laboratory, which provided a space for the development of creative abilities of gifted students and managed to integrate creative workers and students into effective working teams capable of solving complex tasks and creating new solutions. One such task was the implementation of game or competition elements in the process of knowledge acquisition or mastering tasks. It was possible to design the basic framework of a platform that combined the real-artifact and virtual worlds in an ICT environment and to create a hierarchically structured model,

which was piloted in the field of earth resource acquisition and applied in the teaching of students in several high schools (under the guidance of university teachers). The proposed educational product won the first prize of the V4 Raw Materials Ambassadors Schools in Budapest in September 2019.

We have proposed two IETs, one with a tangible platform (preCOVID), the other without a tangible platform. Both had a common and different concept compared to other tools in the way of game implementation and competition elements (level conquest) and variability of individual tasks and items. The innovativeness of the presented tools is on two levels. For the first IET, besides the content itself, there is the rendering of the IET itself in the form of a structured box with progressively unlockable cartridges with individual tasks and the rendering of some of the tasks (the educational set), the designs of which are also subject to intellectual property protection. In the case of the second IET, it is primarily an informal link between a timeline and a quiz built on a broad base of disciplines and areas of human activity. The aim of the research was to verify the functionality of the proposed innovative IET educational tools focused on interdisciplinary issues of raw materials and energy, understanding their role and complexity and the diversity of relationships with emphasis on the attractiveness of education and building stable attitudes to students.

The contribution of the paper is the emphasis on the importance of the positive role of non-conventional educational tools, which use knowledge from different scientific disciplines and allow covering more complex issues of RES. Overall, it will be given more information about effective extraction of the earth's resources in a form that can be more durable and helps to build students' personal attitudes towards the issue, which can then be reflected in the level of practice as well as in the political level.

2. Materials and Methods

The materials were created by the IET and the methodology was oriented towards testing them.

2.1. Content: Professional Background in the Field of Earth Resources' Extraction

When creating the content of the new educational tool, i.e., its content, the complexity of the content was taken into account in terms of the interconnectedness of the individual phases of the formation, acquisition, and use or practical application of individual raw materials, chemical elements, or chemical compounds of which they are the source. For the purpose of the primary design of the innovative educational tool, 12 items (raw materials/elements/compounds) were selected and divided into groups: metals (titanium, chromium, copper, lead), energy raw materials (coal, oil, natural gas, uranium), non-metals (gypsum, talc, salt, sulphur), and mix (quartz/SiO₂, limestone, iron, clay). In addition to the criterion of overall importance (position in the industry), aspects of coverage of variability of the different aspects were taken into account when selecting the individual items.

Energy raw materials (fossil fuels) and their importance are key to understanding the position of renewables in the role of alternative energy sources (from the beginning of the industrial revolution to current climate impacts). The volume of global daily oil consumption, which is around 92 million barrels [38], can serve as a representative indicator, which, if adequately presented, is a good indicator for understanding the quantitative aspect of humanity's use of fossil fuels. The mineral energy source, uranium (a radioactive raw material), is, on the other hand, exceptional in its nature (origin of the element itself; understanding of the meaning of isotopes; accumulation of the useful component in the Earth's crust; and the process of mining, extraction, enrichment, fuel production, fission reaction, reprocessing, production of the artificial element/fuel Plutonium, radioactivity of the fission products, waste management, etc.). The category "energy feedstocks", thus, provides a good basis for understanding the current shape and structure of the sector in terms of providing for the energy needs of society.

The metals' category largely represents the material and technical base of contemporary technology. Copper as a key metal for electrical engineering reflects the state of the

industry. Chromium represents a metal that is important for the production of noble steel types of corrosion-resistant and refractory alloys. It is also an element whose useful minerals come from ultrabasic rocks [39], which is important for understanding the evolution of raw material deposits. Titanium represents a metal with a high added value in its chemical and physical properties, on the one hand, and a paradoxical disparity between its abundant percentage in the Earth's crust [40] and the rarity of its deposits [41]. Lead represents a metal that has been of great importance in technical practice in the past but, which, as an element, is an excellent example to understand the evolution of the elements (the final product of many decay series [42]) and their stability (it is a landmark between radioactive and stable elements in the periodic table of elements [43]). It also serves to document the process of ionizing radiation shielding.

The non-metals' category adds to the range and variability of materials in terms of their origin and importance in their application. Gypsum is a paradox in that not all gypsum is made from gypsum (energy gypsum from the flue gas desulphurization process in coal-fired power stations) [44]. In addition to pointing out the fact that talc is a bulk constituent of drugs, it is useful to use the example of talc to highlight the issue of ensuring the stability of underground works in relation to cohesiveness and other geotechnical properties of the geological environment. Salt is one of the raw materials that has been sought and obtained by humans since time immemorial and whose deposits show the geological evolution of the environment related to the evaporation of seawater (evaporites) [45]. Sulfur, in addition to its occurrence in elemental form, is the basis for the production of sulfuric acid, an important input in the processing of ores, petroleum refining, and a number of manufacturing industrial processes.

The mix category covers raw materials that are used in large volumes as the basis for construction and building materials. Quartz/SiO₂ represents, on the one hand, the basic input for semiconductor production [46] and, on the other hand, quarried aggregates and glass raw materials [47]. Limestone represents the basic raw material for the production of cement [48], lime, crushed aggregate, building stone, and input for production and treatment processes in industry (metallurgy, paper, sugar production) and energy (desulphurization) [44]. Although iron is undoubtedly a metal, on the other hand, in terms of the genesis of deposits, it has a special position because, according to the geologist H.S. Washington [49], iron figures in the group of both petrogenic and metallogenic elements. Iron, as an element located on the boundary between the two groups, has a dual role in nature, participating in the formation of rock-forming minerals as petrogenic elements but also forming typical heavy metal minerals as metallogenic elements. The importance of iron to human society has been increasing since the Iron Age, with the construction industry currently the largest consumer of iron/steel [50]. Clay represents an important raw material with a wide range of uses (production of bricks and building and sanitary ware, ceramics, etc.) and an important link to the development of man and human society [51,52].

2.2. The Process of Creating an Innovative Educational Tool Oriented to the Field of Earth Resource Extraction

The creation of the innovative learning tool was linked to the EIT RawMaterials: RM@Schools project, for which reason standard items such as name/acronym, benefits to be achieved, definition, and structuring of objectives were defined. At the same time, a credo was formulated that captures the main idea of the proposal and reads as follows: "The adventure of knowledge is in the context". There are several other toolkits created under this project to enrich the educational process and to highlight the broader connections between the current economic situation in the world, the circular economy, renewable energy sources, and raw materials, such as FIND the elements (Treasure Hunt 2.0, RawMatCards, RawMatCards, RAWsiko), Materials Around Us (Board Game or Digital version), RockGame, MineralCheck, Recycling of silicon based PV modules, etc. [53].

The proposed innovative educational tool was given the form of a game. The primary task for the players was not to learn or understand something, but to successfully complete

all the tasks of the game in the shortest time. By transferring the tasks to a competitive level and not emphasizing the process of knowledge acquisition or by presenting knowledge of an interdisciplinary nature that is not the primary focus of their curricula in each differentiated learning subject students' prejudices and overall reticence towards the educational process were eliminated.

The game design pursued three sets of objectives:

1. Cognitive goals:
 - To understand the complexity of the issue of resource extraction and earth resources in general.
 - To learn to perceive and identify the relationships between reality and its material background and to understand the key importance of earth resources in this relationship.
 - Gain the ability to understand analogies and model problem descriptions.
 - Gain the ability to extract a problem from its complex verbal formulation or broader description and develop critical thinking skills.
2. Value Goals:
 - Acquire the ability to take an attitude towards things, phenomena, and work activities in their environment primarily in terms of their social, material, and energetic value.
3. Operational Objectives:
 - To acquire the ability to work cooperatively in a team and to deal operationally with tasks of a diverse nature.
 - To learn how to actively use information technology in the educational process and in play at the same time.

As the basic concept of an innovative educational tool, the game was designed into two platforms.

1. Material platform, which is a box containing boxes with objects (artifacts necessary for solving tasks).
2. A virtual platform, which is a tablet containing an application necessary for the implementation of the individual tasks and stages of the game.

2.2.1. Description of the Material Platform

The wooden box itself contains eight separate, removable wooden boxes, each divided by dividers into four compartments. The boxes are stacked in the box to create two horizontal levels, each containing a quartet of boxes. Each level of boxes represents one level of tasks. Each compartment of the box contains a tangible (3D) artifact needed to solve the problem or to better understand the problem under analysis (e.g., a sample of a mineral, a product or material containing the chemical in question, and element or compound, a model or mock-up of an object, etc.).

The boxes placed on top of each other are physically connected to each other by a mechanism containing a lock with a numerical code accessible from the top. The numerical code is four digits. Knowledge of each digit in the code is the result of correctly answering a problem/question from one compartment of the box. In this way, after solving the four problems from one box, the code to unlock the lock can be obtained, so that the box in question can be removed from the box and, thus, the box located underneath it can be accessed. The bottom level box is connected to the bottom of the box in an analogous way. Upon removal of the bottom level box, the bottom of the box is revealed to contain a third level of play consisting of 2D artifacts, panels that are pictures or other two-dimensional aids (such as the periodic table of elements). The sequence and continuity of steps in the game itself is analogous to the sequence and continuity of steps in natural processes associated with the formation of deposits and anthropogenic activities associated with exploitation, work operations associated with extraction of a useful component, the processing of a raw

material into a usable form or its subsequent use, or steps associated with other activities such as waste disposal, recycling, environmental impacts, and the like.

The technical design of the material platform itself has become the subject of intellectual property protection and is protected by a utility model.

2.2.2. Description of the Virtual Platform

The virtual platform consists of a tablet with a web application. The web application is designed and configured to guide the users of the game in a hierarchical, logical, and intuitive way from the beginning of the game until its end. Each question arising from a material artifact contained in the ‘material platform’ of the game will be accompanied by an application, whether at the level of the formulation of the task, support in mastering an activity arising from the task, entering the answer to the question or the results of the task, the use of additional information (aids), the generation of numerical codes, the accompaniment of the game itself, the timekeeper, etc.

Each of the three levels of play, based on a material platform, is ideologically differently oriented. For each problem, items such as the accompanying text (providing relevant information and indicating relationships and connections in addition to an introduction to the problem itself), the wording of the question or problem (formulated in such a way as to clearly define the subject of the solution), the answer choices (multiple (four) answer formulations, one of which is correct), and the aids in the case of an incorrect answer (helping to draw attention to the point of the problem) are formulated.

The first level of the game is focused on the identification of the utility component of an element, a chemical compound, and its source mineral. Either mineral samples (utility mineral, rock) or objects containing or unambiguously representing the main utility component serve as artifacts. Examples of first-level artifacts include:

Coal, a sample of lignite with a distinct structure;

Uranium, a sample of uranium glass and a UV lamp (to induce a luminescent effect);

Copper, chalcopyrite sample; and

Chromium, a sample of electroplated chrome-plated plastic (in this case the product appears to be more illustrative compared to the mineral itself).

The individual boxes of the second tier will represent the same groups of raw materials as for the first tier, and the individual compartments will follow each other vertically.

The second level of the game focuses on the extraction, processing, treatment, transportation, trading, and technological aspects in relation to the raw material or its utility component. Various objects will serve as artifacts, either demonstrating an important characteristic or method, most often using analogies or helping to understand the specifics of the area of raw material extraction and processing.

Examples of artifacts with second-level task descriptions include:

Coal, a wooden block with holes arranged in a regular grid. Marked “pins” are inserted into the holes so that they protrude above the plane of the surface and can be pulled out of the block. This object represents a block of rock containing one or more coal seams. The pins represent the boreholes and will be colored so that the course of the seam in the object under examination can be clearly seen. The thickness of the seam will vary in different places, including its onset or dislocation. The present solution is the educational file and has become the subject of intellectual property protection and is protected by a utility model.

The task is to find out the volume of coal in the examined block, in such a way that the players successively pull out individual pins, which they place on the tablet display at a place where there will be a pair of runners (cursors), which they set to point to the lower and upper boundaries of the strata (Figure 2). They repeat this process with all the pins, at which point the app calculates the volume of coal in the bed. If they have followed the procedure correctly, they will get a result from a certain interval, which will be the correct answer. Among other things, this task is aimed at understanding that we can only “see”

into the rock environment indirectly, and always our idea of the deposit is only a better or worse approximation to reality conveyed indirectly.

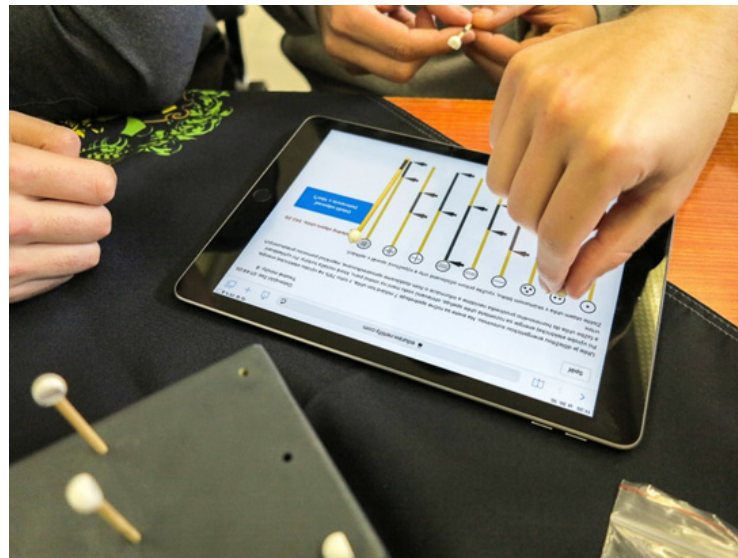


Figure 2. Students using educational toolkit [authors].

Copper, a similar block to coal, but the spikes will have cross lines on them, the density (spacing) of which will represent the pay grade of the deposit. By placing a pin on the scale displayed on the tablet and setting the runner to the appropriate part of the scale corresponding to the line on the pin, the player (competitor) will get an indication of the pay grade ranging from 0.1–1.0%.

The challenge is to match the mining in different parts of the deposit to achieve the desired pay grade in the mined material. This task is aimed at understanding that, in addition to knowing where the useful mineral is located, we also need to know its quality or the content of the useful or, conversely, the harmful component.

Natural Gas, a plastic sphere containing a liquid, which is an analogy for the spherical tanks on LNG carriers, due to the understanding of the behavior of the liquid when moving in a tank of this shape and the importance of the global transport of fossil fuels.

The third level of the game focuses mainly on the area of the use of the raw materials itself or its utility component and the products made from it.

Examples of artifacts include:

Copper, a Picture of a copper brick (used for investment purposes), and

Lead, the Periodic table of elements with radioactive elements clearly marked.

In the final phase of the game, after all tasks have been solved, students/players are presented with a representation of a complex object (in the presented case study it was a hospital) in a virtual platform (via a created application) in a visual, simplified form in cross section, while the task of the contestants is to insert into the picture the symbols of the individual items (chemical elements/materials) that are significantly represented in each object or are behind the supply of energy. Assigning all the items to all the required boxes completes the process of the game itself and the timer stops.

2.3. Evolution of an Innovative Educational Tool (IET) in the Light of the Need for Distance Learning

Due to the limitations of the measures related to the pandemic of COVID-19, it was decided to modify the originally designed educational tool into a form that does not include a material platform and can, therefore, be implemented remotely.

The first part is the creation of a timeline of the use of an item (chemical element/compound/compound). The second part is a quiz covering the different disciplines or areas

of human activity in which the item in question figures. Both parts have been incorporated into the application.

The timeline covers the range from the Paleolithic to the present, and each time milestone is represented by symbols such as hieroglyphics on artifacts from the ancient Egyptian Empire, the Mona Lisa, or the Woodstock Festival.

In the first phase, the competition was set up for two chemical elements or two substances, gold and silicon/SiO₂ (two competing teams).

Substances were deliberately chosen that have an exceptionally long history of use by humans, in order to maximize the range of the timeline and also to highlight the changes in the function and use of these substances throughout history, which were directly related to the development, progress, and changes in society. In the first part, students/competitors were tasked with placing particular events on the timeline (e.g., gold, the first documented gold hoard, the first gold money, the introduction of the gold standard; Si/SiO₂, dating the first flint tools, the first glass, the first silicon semiconductor components).

For the quiz part, questions were worked out in 10 areas (Gold: physics, chemistry, circular economy, sports, astronomy, education, geography, electrical engineering, metallurgy, art; Si/SiO₂: physics, chemistry, agriculture, astronomy, watches, personalities, computing, engineering, geology, geography), the composition of which aimed to cover as broad a base as possible for the use of each of the substances, from the key to the unexpected applications. For each of the 20 quiz questions, a video was produced explaining the answer to the question in an illustrative manner, ranging from 0:27 min to 2:20 min. Examples and forms of demonstration are used, using original perspectives, techniques, and punchlines. The time scale and content are conditioned by the desire to gain maximum attention while fixing the presented information to content with sold value (visual, humorous).

The proposed educational tool has been used in the context of a secondary school curriculum oriented towards interdisciplinary issues of earth resources, environmental protection, climate change awareness, and renewable energy sources.

2.4. Collecting Data from Visits to Secondary Schools and Using Games in the Education Process

Following the completion of the first IET, which took place in 2020, three grammar schools were visited (one day for one school, with the visit lasting 2 h) where 86 students (15–19 years old) and five teachers were involved in the IET trial. Their opinion about the toolkit was collected by interviews, and citations of their answers can be seen in Table 1.

Table 1. Citation of answers obtained in the framework of the implementation of the feedback to the first IET.

Group of Goals	The Text of the Target	Text of the Answers
Cognitive goals	Understand the complexity of the issue of obtaining raw materials and land resources in general.	"We were surprised by the connection between the common things around us and the energy sources and raw materials behind them."
		"It looks like everything around us is completely dependent on raw materials and energies that we don't even know where they come from or what is happening to them."
	To learn to perceive and identify the relationships between reality and its material background and to understand the key importance of earth resources in this relationship.	"Without people knowing to use resources" efficiently, "our society probably wouldn't have developed much and today we wouldn't be where we are in both positive and negative ways."
		"It is already clear that RES are only part of the energy mix and the role of individual sources depends on many factors and is different for each country and economy, and therefore RES cannot be considered as a flat rate solution."
		"Many fundraising activities take place completely outside of us, so we don't think they exist, the more shocked they are of great importance to us."

Table 1. Cont.

Group of Goals	The Text of the Target	Text of the Answers
Cognitive goals	Understand the complexity of the issue of obtaining raw materials and land resources in general.	"We were surprised by the connection between the common things around us and the energy sources and raw materials behind them."
		"It looks like everything around us is completely dependent on raw materials and energies that we don't even know where they come from or what is happening to them."
	To learn to perceive and identify the relationships between reality and its material background and to understand the key importance of earth resources in this relationship.	"Without people knowing to use resources" efficiently, "our society probably wouldn't have developed much and today we wouldn't be where we are in both positive and negative ways."
		"It is already clear that RES are only part of the energy mix and the role of individual sources depends on many factors and is different for each country and economy, and therefore RES cannot be considered as a flat rate solution."
		"Many fundraising activities take place completely outside of us, so we don't think they exist, the more shocked they are of great importance to us."
	Gain the ability to understand analogies and model problem description.	"It's great as you can find in common things chemistry, mathematics, geometry, physics, biology and the like, that's how it makes sense."
		"When we learn such things at school, the connections are not there or no one will tell us."
	Gain the ability to extract the problem from its complex wording or broader description, development of critical thinking.	"I really liked that we went through the individual levels and it was necessary to complete things in order to find the code and go on, we wanted to win."
		"It was probably the hardest thing to understand what the role involved in the coal and copper ore models was, but when you try to imagine it and realize that we have only indirect information about things underground, for example, it started to make sense. "
		"Those tasks with 'sticks' looked pretty scientific, we had to read it a few times to understand what we were supposed to do in the end, but then it went well."
Value goals	Gain the ability to take a stand on things, phenomena, and work activities in your environment, especially in terms of their social, material, and energy value.	"It was interesting to choose from a variety of answers that contained logical reasoning, but only one was correct."
		"Now we understand that each person's actions and attitudes contribute to the pressure on energy and raw materials."
		"We already understand why the recyclability of some things, such as glass, copper, or iron, does not take into account the energy dimension of the problem, which is important to take into account."
		"Replacing all those 100,000,000 barrels of oil a day with another energy source is probably quite unfeasible and at some point soon unrealistic."
		"The link between the size of the human population and its material level and the degree of global environmental, economic growth, and climate impacts are still fully interlinked."
Operational goals	Gain the ability to cooperate in the team and operationally solve tasks of diverse nature.	"The behavior of an individual in the system seems to be important, because of his direct energy consumption but also because of the demands on the raw materials and energy that are in the products he buys and so on."
		"It took us a while to share who would do what, but then it worked well when the tasks were divided; it saved time."
	To learn to actively use information technology in both the educational process and the game.	"The fact that we had those things in our hands was great. The application in the tablet was well done, as such a guide, when we could not cope, so we read it again. The tools were also great after the wrong answer; you clarified enough."

The testing of the second IET, a quiz application, involved two grammar schools (one day for one school, visiting lasted 2 h) during summer 2021 with 42 students. In addition, the application was tested at the SlovakTech event where another 42 students from different high schools were involved. In total, 84 students (15–19 years old) tried the toolkit. The selection of the schools as well as the participating students was random. The procedure was the following:

1. Research questions (A, B, C) were defined for which null and alternative hypotheses (H0, H1) were formulated.
 - The Research question was A: Can education using the tools of interdisciplinary competitions or games lead to a better understanding of the context of earth resource acquisition, compared to conventional education on aspects of these issues covered in individual subjects?
 - A-H0: Education through an interdisciplinary competition or game does not provide a better understanding of the relationships in the field of earth resource extraction than conventional education within individual subjects.
 - A-H1: Education through interdisciplinary competition or games provides a better understanding of the relationships in the acquisition of earth resources than conventional education within individual subjects.
2. In order to test the hypotheses for research question A, a questionnaire was formulated with the following wording:
Is it effective to educate on the subject in the form of a competition or a game?
3. Research question B: Does information in the subject area acquired informally, through tasks fixed to experience, have a more lasting character than that acquired through standard formal channels?
 - B-H0: Information given informally is not of a more permanent nature than the information obtained through conventional sources.
 - B-H1: Information given in an informal way is more durable than information obtained in a conventional way.
4. In order to test the hypotheses for research question B, a questionnaire was formulated with the following wording:
Can information given in an informal way be more lasting than that given in a formal way?
5. Research Question C: Does the fact that the educational competition/game contains any 3D artifacts and tangible objects have an impact on the engaging nature of the educational competition/game?
 - C-H0: The attractiveness of an educational competition/game is not enhanced by enriching it by adding 3D and tangible objects.
 - C-H1: The attractiveness of the educational competition/game will be enhanced by adding 3D artifacts and tangible objects.
6. In order to test the hypotheses for research question C, a questionnaire was formulated with the following wording:
Would the contest be more engaging if it included some tangible artifacts?
7. The subject questions for each research question were included in a questionnaire that also included questions aimed at verifying knowledge.
8. All participants first filled in a questionnaire where there were eight questions focused on students' knowledge about gold and silicon and three questions focused on their opinion about learning through the game.
9. The participants were divided into two teams. Each team chose a captain who was to interact with the toolkit leader and chose an element.
10. A timeline was arranged.

11. There was a quiz (Figure 3), in which students could choose the number of points per question (100, 300, 500) and the area from which they wanted to answer the question. This also allowed them to practice their strategic thinking.
12. The team that had the higher number of points won.
13. Then, after the game, the students completed the same questionnaire again with the same questions.



Figure 3. Innovative educational toolkit application [authors].

Students' responses to the survey questions focusing on their opinion of the toolkit, which were the subject of hypothesis testing, were evaluated using Non-Parametric Related-Samples Wilcoxon Signed Rank Test using SPSS software. The results of the questionnaire as well as the evaluation of the hypotheses are presented in Section 3 Results.

3. Results and Discussion

3.1. Evaluation of the First IET

After the game, qualitative feedback was obtained through dialogue with the student contestants and with the teachers providing the teaching in the schools from which the students came.

The questions asked by the IET designers were largely aimed at verifying that the set cognitive, value, and operational objectives had been met. They were directed to the content area, the formal area, aspects of the novelty of the information, its relevance for further perception of the issue, and the construction of attitudes towards it.

The following findings emerged from the interviews:

- Students perceived positively that they were learning in the form of a game, focusing on problem solving and they did not see the actual taking in of information as learning but as overcoming an obstacle to progress through the game.
- They rated individual tasks from moderately to very challenging. The tasks with the highest level of abstraction (tasks with educational sets) posed the greatest challenge.
- Overall, students expressed interest in this kind of learning.
- The issues presented were largely surprising to the students and many of the facts presented were described as fundamentally new.
- The overall impression of the presented content of the game was the clarification that the human society is directly intertwined with the raw material energy resources, their availability, and rate of use, with an emphasis on energy resources.
- The students largely lost the vision of simple solutions consisting of the quantitative substitution of non-renewable resources (mainly fossil fuels) by renewable resources, which did not reflect other aspects and their limits.

- Students presented concerns about the future direction of human society and the possibility of effectively addressing the problems related to the impact of human activity on the environment and climate change.
- Teachers unanimously expressed a positive attitude towards the implementation of IET in the teaching process as a means of gaining attention and engaging students in the process of acquiring interdisciplinary knowledge through team creative work in solving competitive tasks in the game itself. Educators also expressed surprise at the presented connections between different phenomena related to the use of earth resources. Educators expressed the view that it is very difficult to translate the complex issue of earth resource extraction into individual, differentiated teaching subjects pursuing primarily different objectives.

Specific types of responses are listed in Table 1 according to the group of objectives pursued.

3.2. Evaluation of the Second IET

A total of 84 students took part in the second IET, completing the same questionnaire before and after game, with eight questions focusing on their knowledge and ability to relate information from different areas and three questions focusing on their opinion on supplementing the learning process with such playful learning.

Evaluation of the questionnaire responses revealed the following findings:

- Before playing the toolkit, the mean score for the knowledge questions was 5.4 points, while after playing it was 5.8 points.
- Before the game, none of the participants achieved full points, while after the game, eight students achieved full points.
- Before using the toolkit, 23 students had less than 5 points, while after using the toolkit only 15 students had less than 5 points.
- These findings are also presented in Figure 4.

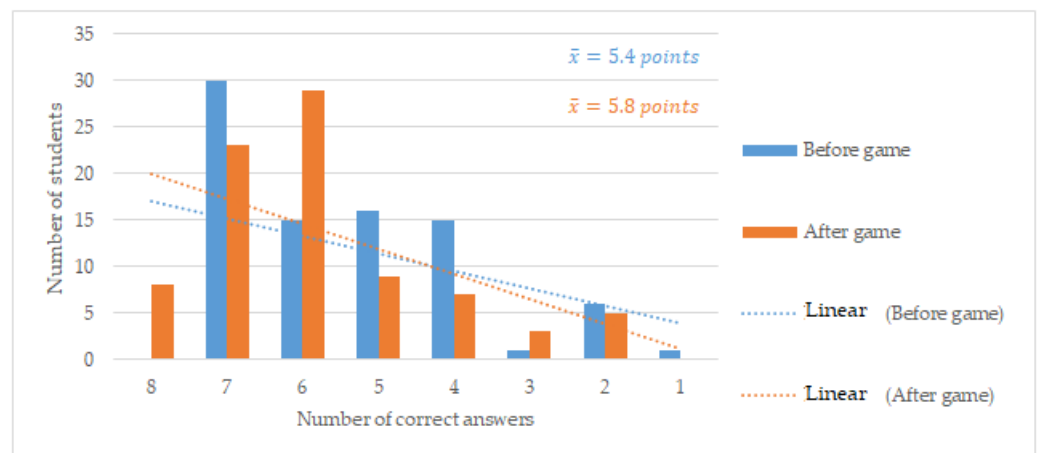


Figure 4. Results of questionnaire for knowledge questions.

In addition to the knowledge questions, hypotheses A-H0, A-H1, B-H0, B-H1, C-H0, and C-H1 for research questions mentioned in 2.4. were verified. The students' responses for the questionnaire are evaluated in the form of graphs in Figures 5–10.

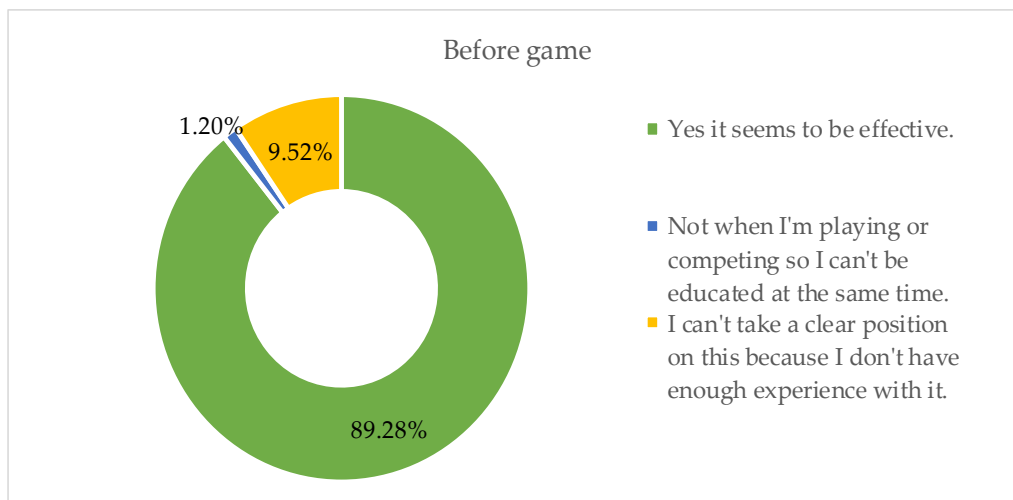


Figure 5. Results of questionnaire for question: Is it effective to educate in the form of a competition or a game? (before using toolkit).

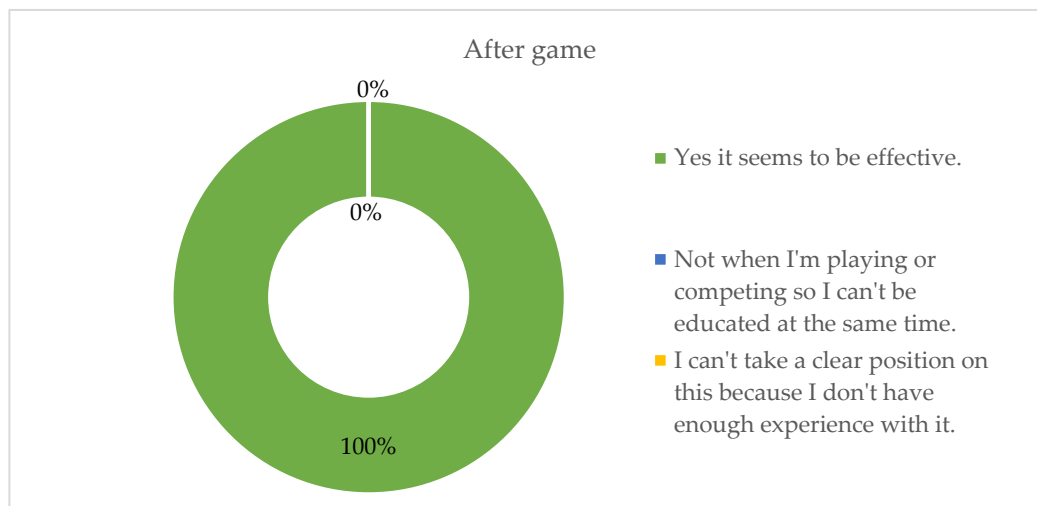


Figure 6. Results of questionnaire for question: Is it effective to educate in the form of a competition or a game? (after using toolkit).

Figures 5 and 6 show that before playing the toolkit, 1.2% of students thought that learning through a competition or game was not effective and almost 10% could evaluate. After the competition, all 84 respondents (100%) agreed that such learning is effective.

Based on the results of the Non-Parametric Related Samples Wilcoxon Signed Rank Test, the A-H1 hypothesis was accepted, i.e., education through interdisciplinary competition or play provides a better understanding of the relationships in earth resource acquisition than conventional education within individual classroom subjects. Hypothesis A-H0 was rejected.

When we asked whether information delivered in an entertaining way can be more enduring than formal education, almost 10% said no before using IET, almost 36% could not say, and over 54% said yes. After the use of IET, 90.47% agreed that information given in this way can be more permanent and almost 10% could not express their opinion.

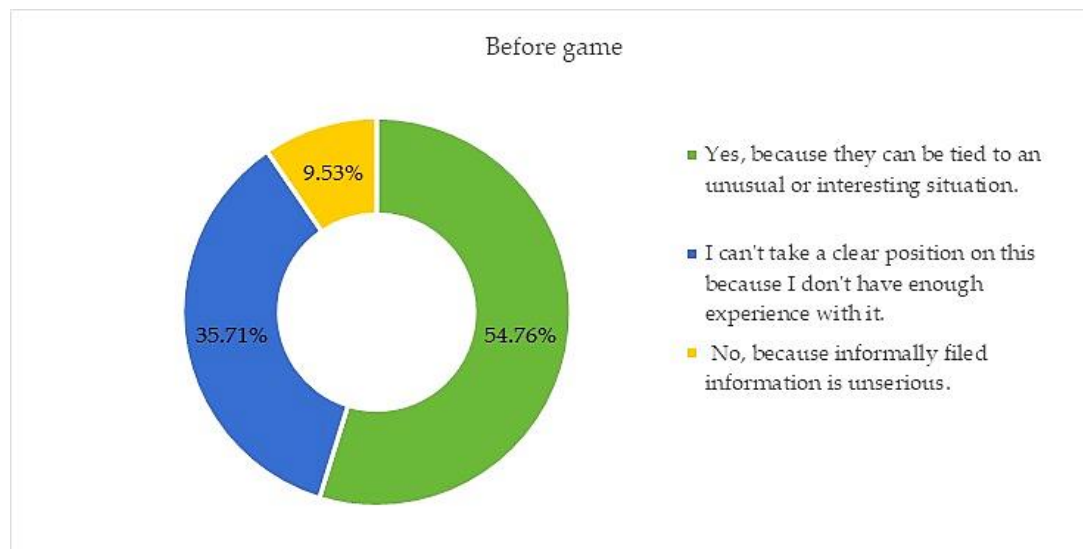


Figure 7. Results of questionnaire for question: Can information given in an informal way be more lasting than formal ones? (before using toolkit).

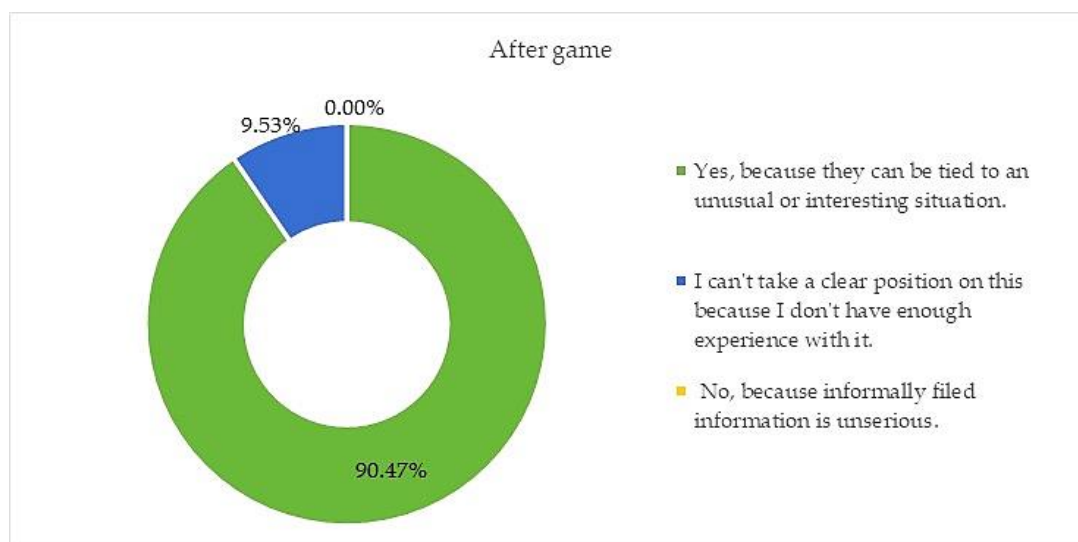


Figure 8. Results of questionnaire for question: Can information given in an informal way be more lasting than formal ones? (after using toolkit).

Based on the results of the Non-Parametric Related Samples Wilcoxon Signed Rank Test, the B-H1 hypothesis was accepted, i.e., the information given informally is of a more permanent nature than the information obtained conventionally. Hypothesis B-H0 was rejected.

Finally, students were asked to answer the question whether tangible artifacts would have made the competition more engaging. Prior to the quiz, the majority of students (54.76%) could not answer, 27.38% said yes, and almost 18% disagreed. After the quiz, all students could answer, with almost 73% of students agreeing that the game would be more interesting with real artifacts and over 27% of students disagreeing.

Based on the results of the Non-Parametric Related Samples Wilcoxon Signed Rank Test, the C-H1 hypothesis was accepted, i.e., the engaging nature of the educational competition/game will be enhanced by enriching it with 3D artifacts and tangible objects. Hypothesis C-H0 was rejected.

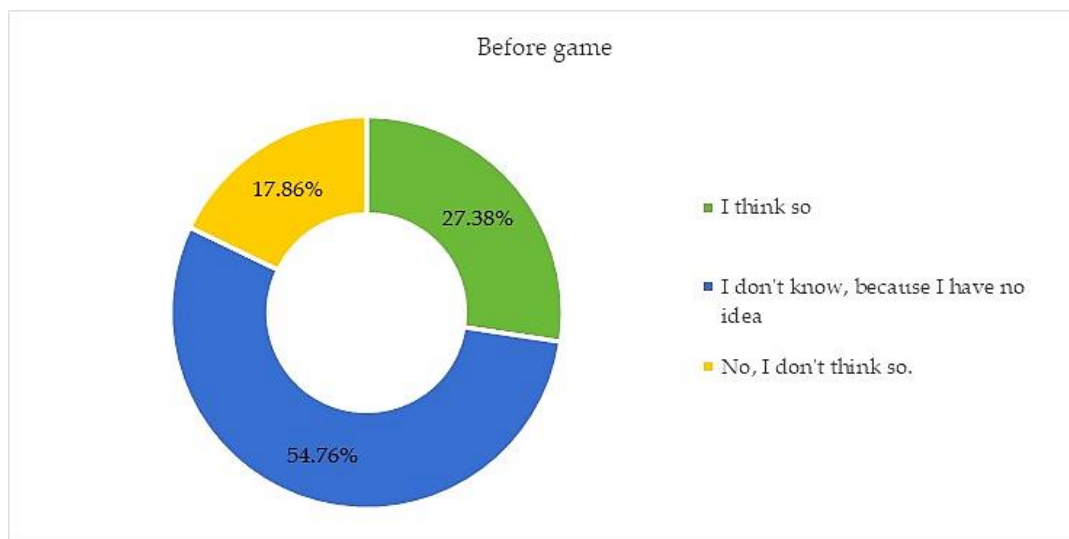


Figure 9. Results of questionnaire for question: Would the competition be more engaging if it included some tangible artifacts? (before using toolkit).

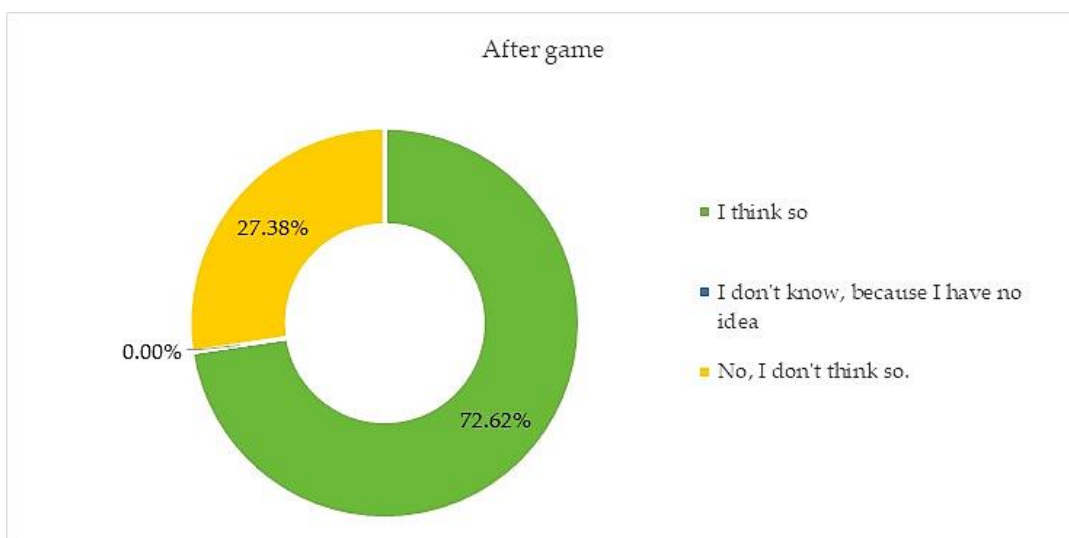


Figure 10. Results of questionnaire for question (Would the competition be more engaging if it included some tangible artifacts?) after using toolkit.

Although significant differences between the number of correct answers before and after the game were expected, we concluded that the use of the toolkit was successful. Indeed, several factors may have influenced the results:

- Before playing the game, students were relaxed and, after the game, which lasted almost 2 h, their attention and concentration were already reduced.
- Students may have felt less motivated to complete the questionnaire after the game, especially the team that lost the game.
- The students who did not improve may belong to a group of students who need a different learning approach other than listening and reading.
- The students were in a hurry to complete the questionnaire and, therefore, they did not pay the same attention to the answers as they did before the game.
- Students did not want to fill out the same questionnaire a second time and, therefore, answered “just so it is”.

However, based on the students’ responses to the opinion questions concerning the testing of hypotheses before and after playing the game, it was evident that the students

had a positive attitude towards the toolkit and were aware of its benefits for the learning process. Additionally, most students agreed that such information is more permanent and that supplementing the quiz with tangible artifacts could further enhance the engaging nature of the competition and bring about more significant differences in the results of correct answers before and after the quiz.

The results indicated that conventional education is not sufficient for a proper understanding of complex issues such as RES and the extraction of raw materials—energy or land resources. It is important to present the information in an interdisciplinary level but at the same time in an engaging form, so that it is sufficient to build attitudes for students and so that there is a prerequisite for better implementation of knowledge in practical life. The proposed IETs can be applicable with different content at different levels of education and also for complex interdisciplinary issues, while, at the same time, they can improve students' attitudes and motivations to receive knowledge. The contribution of the solution lies in the fact that by using one tool, besides the actual knowledge acquisition, aspects of teamwork, working under pressure (time, points), aspects of using ICT tools at work, and motivational and value aspects can be addressed.

4. Research Limitations

This study contains many limitations that also offer opportunities for further research. First, the sampling and data collection were limited to the region, which means that this research has limited empirical applicability. This study focused only on middle and high school students. The age limitation of the students (12–19 years old) was determined by the EIT project itself. Sample size, number of days visited, and time spent in school were affected by the COVID-19 pandemic and schools being closed during the lockdown. If the situation improves during the next year, more schools are expected to be visited, with a larger number of students and teachers being involved in the testing of the extended version of the toolkit.

5. Conclusions

Understanding the comprehensiveness of resource acquisition, the real status of renewable resources and alternative energy solutions, their role and importance for human society is one of the basic prerequisites for the effective transformation of the current form of human civilization towards a more sustainable and less environmentally burdensome form. Given that this is a very complex issue overall and crosses a number of scientific disciplines, obtaining relevant information, forming an objective judgement, and taking a sober attitude towards the issues among the majority population are difficult, and it is advisable to focus already on the educational process.

The educational tools presented in the study were designed to overcome the boundaries defining the individual disciplines reflected in the standard teaching subjects, focusing on the secondary school level, and have the added value of attractiveness and appeal of educational form and content. Two tools were developed, one of which was built more on a physical basis and a face-to-face form of delivery, the other on an ICT platform and a more distance or online form.

The experiences presented with the use of both tools show that, overall, they were positively received by the students. In the validation of the second tool, three research questions were defined and the hypotheses based on them were verified by way of a questionnaire survey. The results obtained confirmed the expectations: All three hypotheses, A-H1, B-H1, and C-H1, were accepted by testing answers of students with Non-Parametric Related Samples Wilcoxon Signed Rank Test in SPSS software and indicated that the presented way of obtaining information/knowledge in the field appears to be promising and effective. The knowledge and skills acquired in this way are of a more permanent nature, strengthen the student's self-confidence, and will be a real competitive advantage for the graduate in the labor market. The results of this paper are in line with the studies mentioned in the introduction. The general results are that the innovations in the educational process have

a positive impact on students' learning and their acquisition of knowledge in the field of interdisciplinary understanding of the world.

The presented findings could also contribute to the effort to objectively perceive the position of the overall importance of the issue of raw material–energy resource extraction in the sense of increasing the chances for the implementation of the necessary changes in terms of possible reduction of the negative impacts of human activity on the environment and the overall transformation of the current global economy towards a more sustainable form. Last but not least, objectively oriented, educated young people will have a better chance of creating a rational form of society in which both they and future generations will live.

6. Patents

The material platform in this paper, Multilevel hierarchically configured box, as indicated in Section 2.2, is protected under Slovakia Law (PUV 50017-2020, Utility model number: 8953).

The material platform in this paper, Educational set, as indicated in Sections 2.2 and 2.3, is protected under Slovakia Law (PUV 50017-2020, Utility model number: 8933).

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