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IMPLEMENTATION OF STEAM PEDAGOGY IN THE HUNGARIAN EDUCATION SYSTEM (FROM THEORY TO PRACTICE)

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Abstract: Under the umbrella of VUCA-world and growing international competition, the pragmatic learning and teaching methods are playing more important role in education. Education systems face their needs of adaptivity and transformation to the 21st century fast-changing environment and challenge of multiple information processes. In this context, inquiry-based learning, development of creative problem solving and innovative thinking are key factors for work, life and literacy. In the first part of the paper, the philosophical phenomena of this process comes from John Dewey 'learning by doing' principle. In fact, the challenges of teaching is based on strengthening intrinsic motivation, developing creative knowledge transfer and constructing applied knowledge. Basically, this is a learning- and learner-centered curriculum planning, teaching methods and formative assessment. Steam Pedagogy has transdisciplinary approach and focuses on creativity, especially creative problem solving thinking skills. In the second part of the paper, the authors introduce and analyze the outcomes and results of Steam Pedagogy in Hungary in practice. Finally, at the end of the paper, conclusions underline some open dilemmas and questions.

Keywords: VUCA-world, John Dewey, 'learning by doing' STEAM Pedagogy

Összefoglalás: *A VUCA-világ és a növekvő nemzetközi verseny árnyékában a pragmatikus tanulási és tanítási módszerek egyre fontosabb szerepet játszanak az oktatásban. Az oktatási rendszereknek szembe kell nézniük az alkalmazkodás és átalakulás szükségességével a 21. század gyorsan változó környezetéhez és a többféle információs folyamat kihívásához. Ebben a kontextusban a kérdésalapú tanulás, a kreatív problémamegoldás és az innovatív gondolkodás fejlesztése kulcsfontosságú tényezők a munka, az élet és az írástudás szempontjából.*

A cikk első részében ennek a folyamatnak a filozófiai jelenségei John Dewey „cselekvés általi tanulás" elvéből származnak. Valójában a tanítás kihívásai az intrinszik motiváció erősítésén, a kreatív tudásátadáson és az alkalmazott tudás felépítésén alapulnak. Alapvetően ez egy tanulás- és tanulóközpontú tantervtervezés, tanítási módszerek és formáló értékelés. A STEAM pedagógia transzdiciplináris megközelítést alkalmaz, és a kreativitásra, különösen a kreatív problémamegoldó gondolkodási készségekre összpontosít. A tanulmány második részében a szerzők bemutatják és elemzik a STEAM Pedagógia gyakorlati eredményeit és kimeneteleit Magyarországon. Végül, a tanulmány végén a következtetések néhány nyitott dilemmát és kérdést emelnek ki.

Kulcsszavak: *VUCA-világ, John Dewey, „cselekvés általi tanulás", STEAM Pedagógia*

Introduction

From the context of the Hungarian education, the effectiveness of the first phase if based on innovation, the local and national innovative capacity of the education system, which is around 15-20% in Hungary. The next important factor of the first phase is - on the one hand - mutual understanding of the educational concept or approach behind the innovation. It means, we need to have significant standards of the concept or approach, shared vision of the process of innovation and relevant outcomes of change. On the other hand, mutual understanding the innovation is based on mapping prior knowledge (beliefs, values and experience) of the different actors (teachers, students and leadership) and collecting best practises on innovation.

Implementation is based on shared vision and effective communication on two required input. Firstly, consistency among the different elements of innovation and mutual understanding of the concept and standards. But the focus of the second phase is action, proactive and progressive mindset regarding the change and innovation. No doubt, there are different attitudes of the actors (teachers, students, leadership) regarding change and innovation, but on the base of mapping prior knowledge and collecting best practices, the level of motivation and involvement on implementation is significantly increasing. At the second phase, interactive workshops, individual and cooperative learning with a lot of discussions are progressive methods to effective implementation. The second phase is based on needs analysis (diagnosis, SWOT- or PEST-analysis etc.) and creating supporting system of the implementation.

1. Context of STEAM
(Science, Technology, Engineering, Arts, and Mathematics)

It is clear that in these days, during the fourth industrial revolution, we live in an ever faster changing, globalized world with main emphasize on competitiveness and productivity. Its basic feature is interdependence which means ever growing influence of inter-relationships and stronger effects on each other. In first approximation these effects appear mainly in the arias of economy, society, and culture. Changes in economy, society, science, and culture deeply influence the world of teaching as well (Vass, 2006). Thus, it is worthwhile to orient our interest on the world of education. Obviously, the world of education is not closed, it is an area open to changes, ready to accommodate to those fast, where the above features of the globalized world have strong influence on the procedure of lifetime learning. Consequently, accommodation to fast changes, competitiveness and goal-oriented approach are now standards of the high-quality education. Putting it simply, the features of the globalized world leads to basic changes in the teaching-learning processes. Considering the deep structure of education, in other words its practice, reforms the didactic triangle of planning-development-evaluation. Eventually, economy and society recognized much earlier the value of adaptation to changes than the world of education. Honestly, pedagogy is still trying to catch up with the events. However, it is encouraging (with some optimism) that innovational movements start appear stronger in the last decades in education as well. A significant example is STEAM, well known in both local and international circles. Before treating the main subject of this paper, it is worth mentioning that the above features of globalization, especially in economic and arts sciences the experts call „VUCA (Volatility, Uncertainty, Complexity, Ambiguity) world" (Bennis & Nanus, 1985) (Bennett & Lemoine, 2014) (Mack, et al., 2016). This expression starts spreading in education as well, it is discussed at conferences and in publications. (LeBlanc, 2018) (Reeves & Reeves, 2015) (Sarid & Levanon, 2022) (Szűcs, 2020) (Vass, 2020) (Waller, et al., 2019) According to this concept a general feature of the VUCA world a changed knowledge and learning picture of the 21st century (Zhao, 2015). t two basic pillars are complexity and transversality. Note bene, in the present work both the complexity and transversality features of education are relevant. One of those areas is STEAM.

2. Basic Principles of STEAM Education

STEAM (Science, Technology, Engineering, Arts, Mathematics, earlier STEM) aims at the integration of science, technology, and arts, Clearly, the main subject of this integration is economy. Without claiming completeness and concentrating on education, we wish to emphasize the subjects of knowledge and competence. Knowledge in general includes the properties of information society, the knowledge society and the whole-life studying as well (Vass, 2020). Scientific evaluation of knowledge gave - not surprisingly - many pedagogical results. In The world of education prevailed the competence-based teaching, and in the context of whole-life studies the development of key competences got the main emphasize.

> „Key competences are those that everybody needs for self-fulfillment and development, for job-hunting, for fitting in society, for sustainable life, for successful life in peaceful societies, for health-oriented life and for active citizen roles." (Recommendations, 2018)

These key competences are the following: competence in reading-writing, foreign languages, mathematics, natural sciences, technology and technical sciences, digital world, that in learning, personal, social, and studies, competence in citizens' movements, entrepreneur (business world), cultural awareness, and the ability to communicate (Recommendations, 2018). Our present study is related to the competence in mathematics, and in natural sciences, technology, and technical sciences.

> „Competence in natural sciences means an ability and willingness to use available knowledge and methods - including observations and experimenting - for explaining the natural world, in order to recognize the problems and to draw conclusions based on evidence. Competence in technology and engineering sciences is an answer to human efforts to apply the above competence to fulfill human needs or will. Natural, technology, and engineering competence includes understanding the changes caused by the human activities and also the responsibility of the individual citizen." (Recommendations, 2018)

It is worth noting on the one hand the integrated treatment of mathematical competence together with those in natural sciences, technology and engineering, and on the other hand the transversatility of key competences (Vass, 2017). It brings us closer to understanding the basic principles of STEAM, if we separate observation, experimenting, problem recognition, conclusion making based on evidence, application of knowledge, understanding of changes, and individual responsibility. The consistent structure of knowledge, skill, and attitude in the above competence area helps to apply the pedagogic principles in practice.

> „Science, technology and engineering knowledge includes the principles of the natural world, basic scientific concepts, theories, principles and methods, technology, technological products and processes, and science, technology, engineering and in general understanding the impact of human activity on the natural world. As a result, these competencies should enable individuals to better understand the societal benefits, limitations, and risks (in relation to decision-making, values, moral

> issues, culture, etc.) of scientific theories, applications, and technology. Skills include an understanding of science as a process of inquiry through specific methods, including observation and controlled experiments, the ability to think logically and rationally to justify assumptions, and the willingness to discard one's own beliefs when the new experimental findings include contradicting results. Skills include the ability to use and modify technological tools and machines and scientific data to achieve a goal or to make an evidence-based decision or conclusion. The individual must also be able to recognize the basic features of scientific research and communicate the conclusions and justifications leading to them. Competence includes an attitude of critical evaluation and curiosity, consideration of ethical issues, and support for both safety and environmental sustainability, especially in the context of scientific and technological advances affecting ourselves, our families, our communities, and global issues." (Recommendations, 2018)

From the point of view of relevant knowledge, it is worth emphasizing the importance of understanding the processes. In the case of skills, thinking and decision-making are decisive, and in terms of attitudes, criticality and curiosity.

Last, but not least, with regard to transversality and the pedagogical principles of STEAM, it is worth emphasizing the following:

> „Key competencies are all equally important; each has a role to play in being able to live a successful life in society. Competencies can be used in many different contexts and in many different combinations. They overlap and intertwine; elements essential to one area support competence in another area. Skills such as critical thinking, problem solving, teamwork, communication and negotiation skills, analytical skills, creativity and intercultural skills are part of all key competences." (Recommendations, 2018)

It is not a negligible factor that a close correlation can be shown between the knowledge economy and the quality of education. In simpler terms, the quality of knowledge is the key to the development of a given country (Hanushek & Woessmann, 2009) (Hanushek & Woessmann, 2015a) (Hanushek & Woessmann, 2016) (Hanushek, 2019). The integrative nature of STEAM can provide answers to the challenges of both competency-based character and education quality. The narrower interpretation of the knowledge economy brings us closer to providing the answers, according to which, when examining the interdependence of the economy and education, the basis is actually the ability to innovate and learn (Tamási, 2006) (Vass, 2020). This is well indicated by the concept of the skill gap, according to which there is a „skill gap" between the economy and the world of education, which clearly indicates that the world of education can adapt more effectively to the above changes by developing competencies, which obviously affects quality as well.

Summarizing the pedagogical principles of STEAM, it is worth emphasizing activity-centeredness, action-oriented, „Learning by doing" pedagogy, pragmatism and experiential learning.

3. Examination of the Basic Principles of STEAM Pedagogy

The pedagogical principles of STEAM should be examined on two levels in the light of Hungarian educational traditions and the content and methodological innovation of recent decades, at the level of the curriculum content and the innovative learning-teaching methodology. It is a fundamental fact that the system of domestic content regulation and the practice of planning culture have been curriculum-centered for centuries, with the "What do I teach?" question being in the foreground. In our view, the basic pedagogical principles of STEAM, at the first level, change the curriculum focus of design culture. STEAM is curriculum content, which means that instead of pieces of curriculum for subjects (mathematics, physics, chemistry, biology, music, drawing, etc.), it presents a more complex, inter- and trans-disciplinary curriculum content. In this case, the curriculum has no primacy, the curriculum content is a tool for development (Vass, 2007). At the second level, STEAM as curriculum content actually means the curriculum planning of the previously mentioned key competencies. In this case, the curriculum content is the development process itself (Costa & Liebmann, 1997). The curriculum is presented not as a quantitative but as a structural design challenge. Curriculum grids and maps, modular design are brought to the fore (Drake, 1993) (Jacobs, 1989) (Jacobs, 1997) (Vass, 2019). Certain elements of the above planning paradigm shift can also be seen in action in the National Core Curriculum published in 2020. It is worth continuing the investigation of STEAM as curriculum content in the case of domestic standards. Although STEAM expressis verbis does not appear in the National Core Curriculum, active learning, learning activities, the development of student competencies and the creative application of knowledge, individualized learning opportunities are already included in the government decree as a basic principle. In addition, in the case of science education, you can read the following:

> „In order to develop natural science knowledge and especially mathematical, natural science, engineering-technical and IT (hereafter: MTMI) skills in the 11th grade of high school for students who do not study a natural science subject in an increased number of hours or in a faculty, with a complex approach based on the examination of phenomena must take a taught subject that expands natural science literacy, or one of the integrated natural science modules, physics, chemistry, biology, geography taught according to the above principles, in a time frame of two hours per week." (Kormányrendelet, 2020)

It is clear that the development of MTMI skills is a relevant part of STEAM pedagogy, the complex approach and the emphasis on subject integration prove this. Unfortunately, the arts are missing from the above complexity and subject integration. From the point of view of the integration of the EU key competences, we have a similar feeling of lack, since among the general competences that span the fields of learning, the previously mentioned competences related to natural sciences, technology and technical sciences are missing. However, it is joyful that in the latest version of the National Core Curriculum, the competences of creativity, creative creation, self-expression and cultural awareness are highlighted. Examining the areas of literacy, regarding the realization of the basic pedagogical principles of STEAM, it gives reason for some optimism that in the case of the literacy area of Natural Science and Geography, we can read the following:

> „ During the planning of learning and teaching, the typical personality development of the student, from natural childlike curiosity to the acquisition of scientific knowledge, must be taken into account. With learning methods based on the active participation of students, the joint development of content knowledge and abilities, and the building of knowledge in social interactions, must be made possible. In this, the interest of the student can be given more space, who can analyze the investigated phenomena in the context of several scientific fields, using the opportunities provided by information and communication technologies." (Kormányrendelet, 2020)

> „… the aim of the natural science subject is to integrate this complex body of knowledge by elucidating the fundamental connections between individual natural systems. In the learning-teaching process of natural science, the knowledge of problems relevant to the student and life-like situations plays a fundamental role, which the subject can achieve by discussing the problem in an integrated way, with the active participation of the students, and by planning, performing, observing and analyzing simple experiments - which can even be carried out at home. It is very important to complement all of these with field activities, which do not only mean investigations in nature, but can also be carried out in an urban environment. Experiential, practice-oriented, so-called context-based curriculum processing that is close to the student's thinking and problems is more effective because it ends with the systematization of knowledge." (Kormányrendelet, 2020)

It is not a negligible factor that the above applies not only to the design, but also to the innovative learning-teaching methodology. More complex thematic units, curriculum content and modules will undoubtedly appear in the planning of local pedagogical programs, but we are still in the infancy of effective, inter- and transdisciplinary, structured planning of STEAM. As we have seen, methodological aspects also appear in the National Basic Curriculum, in close connection with competence development, in addition to planning. Experiential, problem-solving, research/inquiry-based learning and the project method are indicated. This is based on a changed image of knowledge and learning. Nota bene, the quality and organization of knowledge is fundamental in creating a balance between declarative (knowing what) and procedural (knowing how) types of knowledge. In addition to creating a balance, there is one more challenge to deal with in the VUCA world regarding the changed concept of knowledge. Namely, understanding processes and the applicability of knowledge strengthen knowledge and creative knowledge transfer (Vass, 2020). At the same time, it is more about it. Báthory states this not by chance: „ Expanding the concept of knowledge to include skills and abilities promises the possibility of a narrow interpretation of knowledge and thereby overcoming the traditional „educational" school." (Báthory, 2000) quoted by (Vass, 2020). Considering the changed image of learning, STEAM prioritizes a broader interpretation of learning. Perception, perception, memory, imagination, thinking, emotion, will, and action are decisive in this (Báthory, 2000).

4. Implementation of STEAM Pedagogy

The traditional meaning of implementation „the act of putting a plan into action or of starting to use something" . „Act" and „use" indicates, that this is a proactive process, which is based on a „plan". Accroding to the more complex definition: „Implementation is the execution or practice of a plan, a method or any design, idea, model, specification, standard or policy for doing something. As such, implementation is the action that must follow any preliminary thinking for something to actually happen." On the base of classification and differentiation of the object on implementation under the umbrella of proactive process, implementation is a complex process from plan via method, standards, to action, which is based on practice.

In fact, the complex process of implementation is related to change management, where complextity has three different phases: initiation, implementation and institutialization. (Fullan, 2007)

> „INITIATION is the first phase of the change process. In most cases, those facilitating and leading change pay close attention to launching the innovation because they recognize that how well something begins affects how it ends. Yet launching an initiative is only the beginning." (Fullan, 2007)

From the context of the Hungarian education, the effectiveness of the first phase if based on innovation, the local and national innovative capacity of the education system, which is around 15-20% in Hungary. The next important factor of the first phase is - on the one hand - mutual understanding of the educational concept or approach behind the innovation. It means, we need to have significant standards of the concept or approach, shared vision of the process of innovation and relevant outcomes of change. On the other hand, mutual understanding the innovation is based on mapping prior knowledge (beliefs, values and experience) of the different actors (teachers, students and leadership) and collecting best practices on innovation.

> „IMPLEMENTATION is the second phase of the change process. Once the vision of institutionalization is clear and consistent, leaders concentrate on what is needed to put the innovation into practice by planning for and supporting implementation." (Fullan, 2007)

Implementation is based on shared vision and effective communication on two required inputs. Firstly, consistency among the different elements of innovation and mutual understanding of the concept and standards. But the focus of the second phase is action, proactive and progressive mindset regarding the change and innovation. No doubt, there are different attitudes of the actors (teachers, students, leadership) regarding change and innovation, but on the base of mapping prior knowledge and collecting best practices, the level of motivation and involvement on implementation is significantly increasing. At the second phase, interactive workshops, individual and cooperative learning with a lot of discussions are progressive methods to effective implementation. The second phase is based on needs analysis (diagnosis, SWOT- or PEST-analysis etc.) and creating supporting system of the implementation.

> „INSTITUTIONALIZATION occurs when the innovation becomes routine practice in its frequency, consistency, accuracy, and results. Members of the organization use the change at least at the routine level of use and have resolved major issues related to its implementation, such as resources, time, materials, and so on." (Fullan, 2007)

The third phase requires, on the one hand, innovative mindset of the different actors (teachers, students and leadership) in order to reach routine level.

> „The innovator's mindset can be defined as the belief that the abilities, intelligence, and talents are developed so that they lead to the creation of new and better ideas." (Couros, 2015)

On second hand, institutialization is based on collaborative professionalism.

> „The collaborative professionalism is about how teachers and other educators transform teaching and learning together to work with all students to develop fulfilling lives of meaning, purpose and success." (Hargreaves & O'Connor, 2018)

In fact, without supporting system of the three-phase process, innovator's mindset and collaborative professionalism are important requirements of institutialization, but this is not the level of systematic change. Supporting system contains four pillars in the context of the Hungarian education.

- Research, development and innovation.
- Learning and teaching materials¸trainings and workshops, tools for curriculum planning, learning and teaching, and assessment, digital tools.
- Organizational innovation-based culture and learship competencies.
- Effective communication and dissemination. (Vass, 2008)

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5. Practice STEM and STEAM in Hungary

The abbreviation STEM (Science, Technology, Engineering, Mathematics) includes only the real sciences, it lacks the creative side. They realized that scientists, engineers and mathematicians could not do their work as successfully without creativity as when they used the opportunities provided by the arts. This is how STEM was transformed into STEAM pedagogy (A = Art). Today we know the surefire recipe. In order for creations and innovative ideas to be realized, a „drop" (or even more) of creativity must be added to the experiments. But it also works the other way around, whether it's musicians, painters, sculptors or even poets and dancers, who are often inspired by science to enhance their production. In STEAM pedagogy, the Art element is at the center, which makes the integrated curriculum much more balanced.

5.1. Music Physics

Sound is a part of our lives and works in us even if we are not aware of it. We hear sounds when we talk, listen to music or just walk in nature. Sounds create special feelings in us, help us communicate and express our emotions. However, sound is much more than just a superposition of sound waves.

Sound has cultural, artistic and scientific significance as well. Musical sounds, played on excellent instruments, represent the pinnacle of human creativity and artistic expressiveness. However, animals and plants living in nature are also able to communicate using sounds that the human ear cannot perceive. In this study, we take a comprehensive look at sound, examine the differences between human and animal sound perception, and show how sound is used in different literacy domains, such as music, art, science, and communication. Furthermore, we present the connections between human creativity and sustainability through the example of musical instruments made using waste materials.

When teaching the laws of physics, students are surprised when a teacher sings or plays an instrument. We can use this kind of interest in many cases during novel learning processes. For example, musical analogies can be used to show how the planets of the solar system move in their orbits according to Kepler's laws. The musical score from 1619 and shown in Figure 1, shows a part of Johannes Kepler's work Harmonices Mundi, the cosmic symphony of the 6 planets known to him. The distance of the planets from the Sun, the size of their orbits, their shape (eccentricity) and the resulting change in speed determine what sounds can be attributed to their movement. Thus, with the help of basic musical knowledge, we can get to know and discover the wonderful system in which our Earth is located in an exciting way. The planets of the Solar System, with the exception of Venus, revolve around a star located at one of the focal points of the orbit in elliptical orbits that differ to varying degrees from the circle, which is why their distance from the Sun is constantly changing. Meanwhile, the magnitude of the gravitational force acting on them also changes, which the body can only compensate for if the planet moves at a higher or lower speed. As a result, our planets play different „melodies" during their orbit around the Sun. In such an example, students can understand that Venus, which always „sings" with the same note, moves in a circular orbit, so its speed is the same near the sun and far from the sun, and since its pitch is lower than that of the planet Mercury, we can also guess that that it is farther from the Sun. [1]

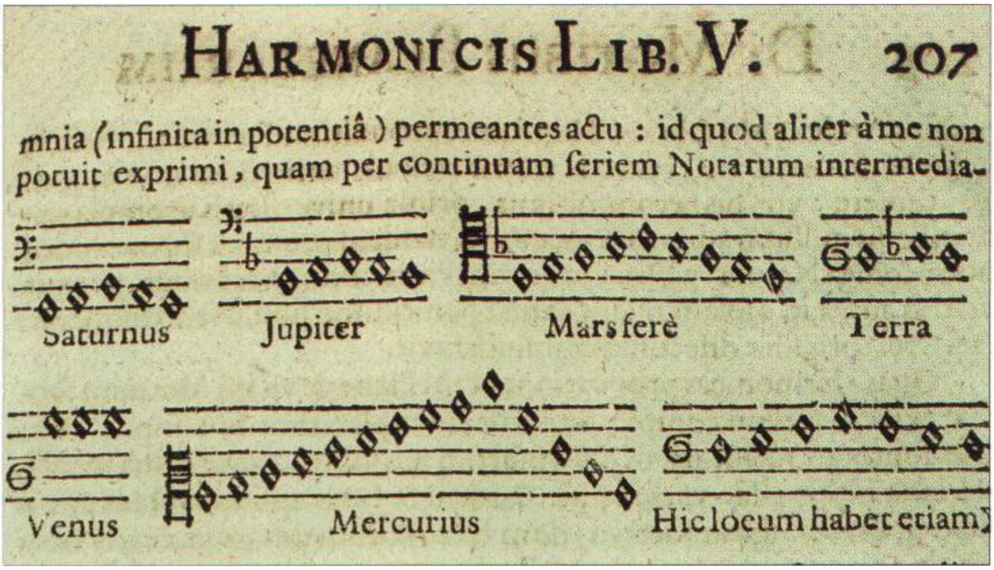


Figure 1. Kepler-Harmonices mundi-V-1619 [2]

Students easily forget what they hear, „Tell me and I will forget", maybe they better understand what they have seen. „Show me and I may remember", but we can actually achieve long-term results with the so-called „hands-on mind-on" learning, „Involve me and I will understand". In simple terms, the hands-on minds-on approach refers to active learning. So, one is combines being both physically and mentally active when it comes to learning. The hands-on minds-on approach is very effective when focusing on encouraging students to be physically engaged whilst they are learning. When children are physically engaged as well as mentally engaged, they are activating different parts of the brain. Therefore, they are strengthening two development processes at once, which leads to a stronger learning foundation. A highly successful project task for younger, but also older students, when we make musical instruments with an almost very small budget, from objects and waste found in the household, putting sustainability at the fore. These objects found in the apartments can also be used to play music and, in addition to the artistic experience, we can also get to know the scientific background of the instruments, the laws of physics gain meaning during the exercise.

We will present some of them in the following, but the storehouse of ideas is inexhaustible, the students come up with new and new ideas during the tasks, the project is constantly developing. In Figure 2, we can change the pitch of the sound by manually turning the so-called „smell tube" under the sink, which is one of the kitchen fittings, at variable speeds. And since a higher speed corresponds to a higher frequency, we can emit a higher musical sound with the pipe. With some practice, we can also play well-known melodies by continuously changing the peripheral speed at the end of the tube.

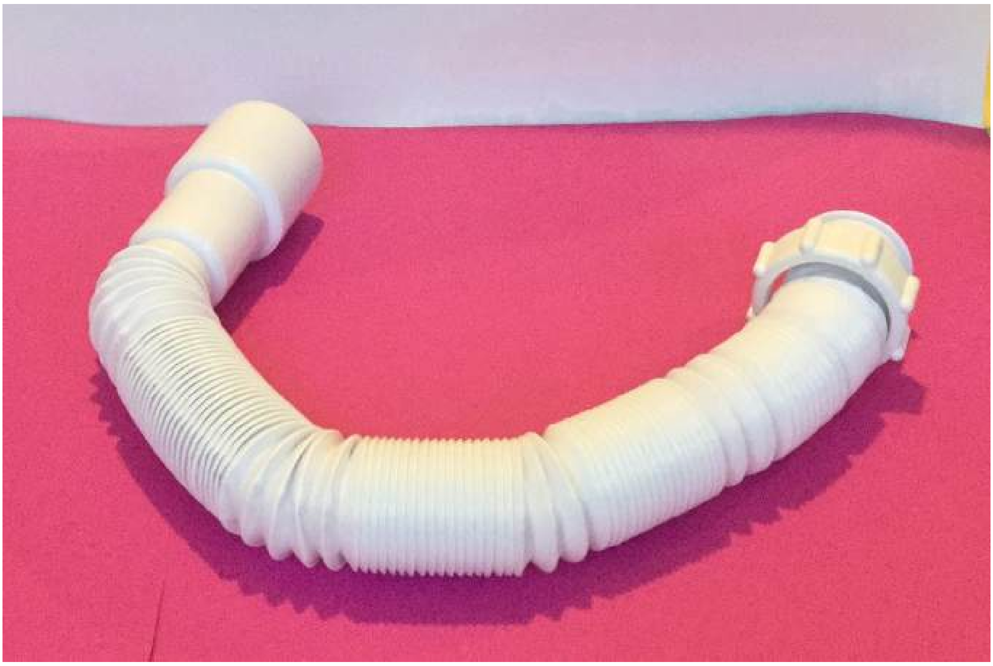


Figure 2. The pipe under the kitchen sink as a musical instrument

In addition to the frequency, the musical sound can also be characterized by another quantity, the length of the sound wave. The following relation can be given between the wavelength and the frequency:

$$c=\lambda\cdot f$$

where c is the propagation speed of the sound wave in the given medium, λ is the wavelength, and f is the frequency of the sound. Even with basic mathematical knowledge, we can notice that there is an inverse proportionality between wavelength and frequency at a constant propagation speed. In practice, this means that at longer wavelengths (the air column is longer or the water column is higher in the container) the frequency is lower, which is equivalent to a lower musical pitch. During the project, the students experience the relationship between frequency and pitch by playing several self-made instruments. Soft drink bottles filled with different amounts of water can be seen in Figure 3. (A), which can be sounded by blowing and plastic pipes cut to different sizes shown in Figure 3. (B) by tapping. Wavelengths and frequencies can be determined by measuring the water and air columns. Through the active activity of the students and the involvement of artistic connections, they can acquire more experiential and lasting knowledge, which is the essence of STEAM pedagogy.

Figure 3. (A) Soft drink bottles filled with water at specific heights,
Figure 3. (B) PVC tubes cut to specified lengths

If we assign different colors to musical notes, we can read sheet music even without serious musical knowledge, with the help of the so-called „rainbow sheet music”. The musical notes in the melodies are replaced by colors, which we also mark on our homemade instruments. The sheet music of a lovely children’s song waiting for Santa can be seen in Figure 4.

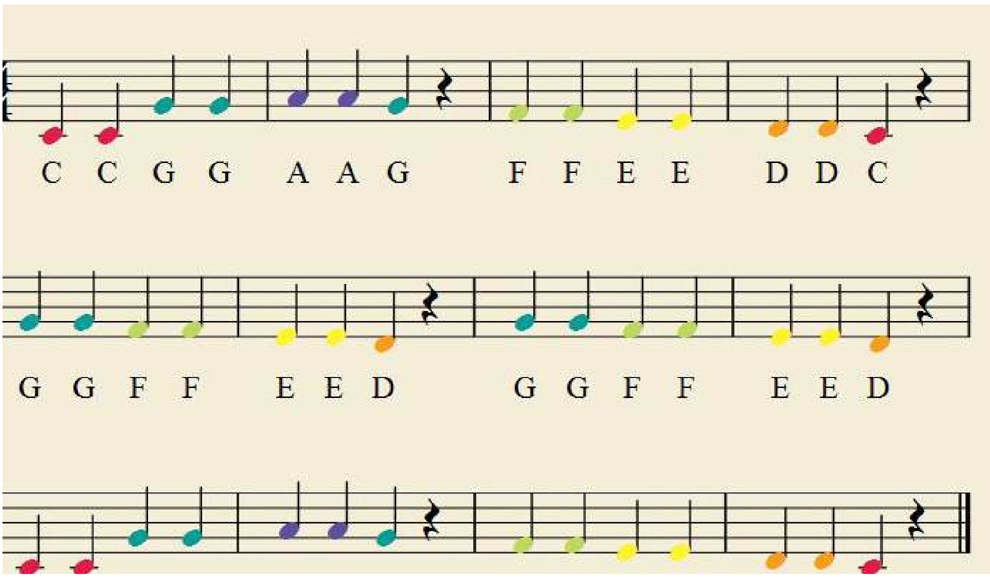


Figure 4. Rainbow sheet music of children’s song

With the help of other household waste (PET bottles, bottles, etc.), either by filling them with water or using the air in them, children can make very cheap and environmentally friendly musical instruments. The students go through a learning process with the help of self-made musical instruments, during which they not only learn the curriculum much more deeply, but they can also come up with innovative ideas and develop the project together with their peers and teacher. Attitude, interest and motivation increase significantly, the effect exerted by music affects the mind and emotions as well. A band made up of students also has a team-building effect, in Figure 5 you can see how cheerfully and joyfully they play music on their simple instruments.

Figure 5. A band of high school students

The first step in making musical instruments is for students to learn about the various methods of sound production. For example, for wind instruments, the wedge, funnel or reed types. At reeds the periodic movement of the tongues produces the sound. An easy-to-make instrument that works on this principle is the „straw trombone". We created the reeds with scissors and pliers, then with the help of a thicker straw we were able to change the length of the tube of the instrument, similar to the trombone, and thus we achieved the different frequencies, thus the melodies. This process is shown on Figure 6.

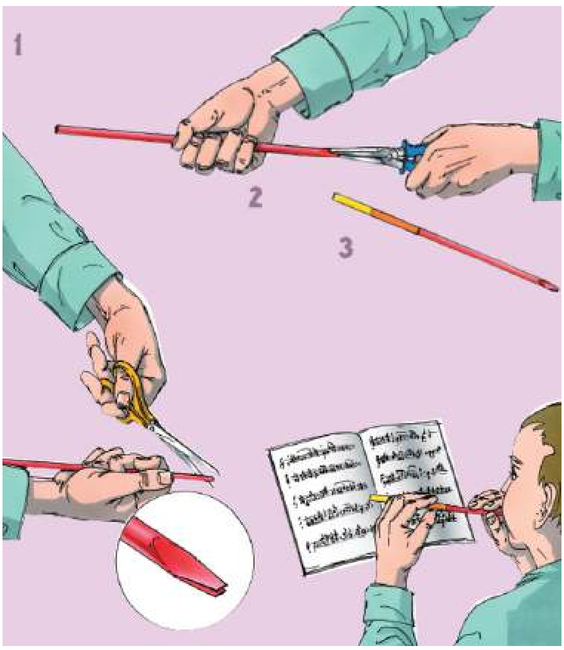


Figure 6. Flow diagram for the production of a „straw trombone" with a reed.

The wedge-type instrument divides the blown air stream into two, during which periodic eddy currents are generated. Excellent flutes and Shepherd's pipes can be made from KPE pipes. The holes drilled in the right place make the instruments suitable for playing in the ensemble, instead of the bottom hole for the octave changer, we can double the frequency by increasing the air flow.

The nozzle of the funnel-type instruments shown in Figure 7 was made using a 3D printer to which we attached ordinary slag and a PET bottle funnel. Here the vibrations of the lips produced the sound, which was amplified by the body of the instrument. The highest sound performance was achieved with these devices.

Figure 7. Self-made funnel-type instrument

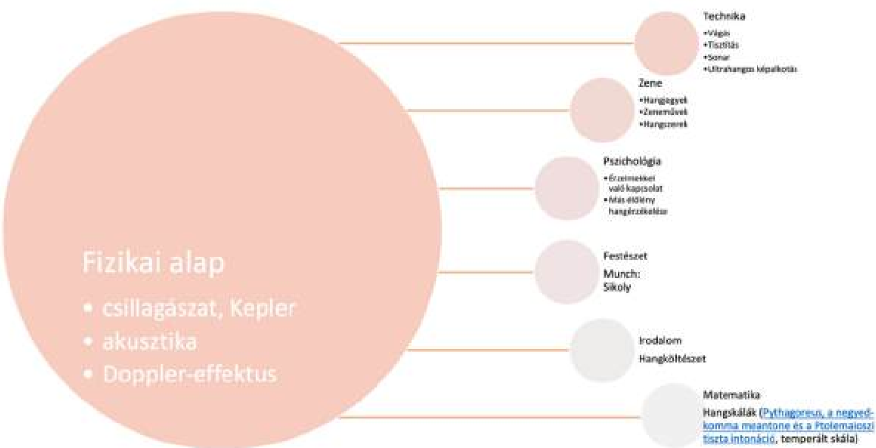


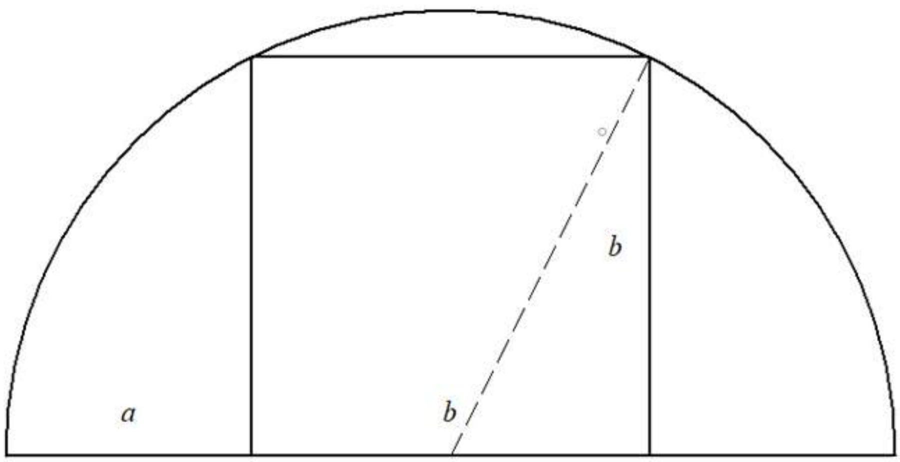
Figure 8. The inter- and trans-disciplinary figure of sound

The inter- and trans-disciplinary essence of sound (Figure 8) is an integral part of human culture, it can be found in various areas and influences our lives. Its physical foundations are rooted in the field of acoustics, where the propagation and properties of sound waves can be studied. In the field of music, sounds are expressed in musical scales and rhythms and evoke emotions in people. Through technology, sound engineering and sound recording make it possible to capture and share live music experiences. From a psychological perspective, sounds can have a profound effect on emotional states and reactions. Pitch and rhythm can be captured and analyzed through mathematics. The inspiring and expressive power of sound, which inspires artists and creations, also appears in painting and literature. These connections show that the study of sound spans many fields and deeply influences art, science, and our daily lives.

5.2. Golden Ratio

The golden ratio, the ratio referred to as the golden or divine ratio, has come a long way in contrast to simple ratios in our civilization since ancient times. It has a place not only in mathematics, but also in the sciences and arts related to nature. In the study of nature, we often come across this ratio as the harmony of the whole and the parts, and in the arts in connection with the harmonious breaking of profane symmetry. But we must not forget the mystical connection of the golden ratio to faith and religions (Hámori 1994). This mysticism still lives today mainly in esoteric writings, in which the methods of science are no longer desirable. The question arises, how should we introduce the above ratio to the school, how should our students first encounter this area of research, which has extensive literature?

Figure 9. A The diameter of the circle passing from the bisector of the square side with side b through the vertices of the opposite side is 2a+b, where b/a= Φ.



As an incomprehensible, but to be followed divine ratio, or rather an approachable, predictable, but at the same time necessity that can be seen in action in our environment and even on our bodies? During a possible experimental processing of the topic, the students experience the relationship of proportion with aesthetics. During the implementation of the tasks in the article, the students made several observations and formulated new measurements in a creative way.

The first written trace of the ratio Φ appears in Euclid's Elements (ca. 300 BC), where the author mentions it as one of the steps in editing the pentagon. Since that time, countless edits have been published, perhaps the simplest editing procedure is the following (Figure 9.).

The problem, known until then as the extreme and intermediate ratio, gained special importance only much later: at the end of the XV century, based on Luca Pacioli's work: Divina proportione, drawings of which were made by Leonardo da Vinci himself. Based on his theory, he sees a general natural law in the exact mathematical formula. In his writing, the created order of the world and the mathematical rule of artistic beauty seem to be formulated. In the earlier writings of the Roman architect and military engineer Vitruvius (around 80-70 BC - after 15 BC), Pacioli believes that he has already discovered the „divine proportion", and the golden ratio will soon become one of the guiding ideas of the entire Italian Renaissance. His train of thought is clearly outlined: if the main ratio of nature has been found, nothing is more natural that the works of art of „true" artists are also made according to this kind of composition, so the possibility of objectively „classifying" works of art and artists is provided based on the ratio.

Kepler also enthusiastically searched for the formula for the harmony of the world, believing that regular bodies could be inserted in a row between the spheres (spheres) carrying the six planets known at the time (Mercury, Venus, Earth, Mars, Jupiter, Saturn). Kepler saw the endless process of rebirth in the golden section: „ This geometric ratio could, I believe, be the idea of the Creator to introduce the generation of like from like."

Certain stages of crystal development also correspond to this principle, when the proportions of the elementary crystal cells are the same as the proportions of the macroscopic crystal body. (Another issue is that this ratio is not necessarily related to Φ.) The physical laws forming the crystal cell determine not only the form but also other physical-chemical properties (material quality) of the macroscopic body, while crystal defects show the influence of the environment. In the flora we also find self-similar species (e.g. myrtle), or the arrangement of leaves, petals and fruits in accordance with the Fibonacci sequence (e.g. sunflower, pagoda cauliflower), but obviously the influence of the environment is even more significant than plants, so the deviation from the ideal, the number of defects is significantly higher than in crystals. In the animal world, the most frequently mentioned examples of the golden ratio are the Nautilus octopus and the five-pointed star. Their growth is characterized by maintaining proportions in a non-strict sense, but the rather strong environmental influence of the animal world leaves much deeper traces in the development of individual species than in plant populations, which could even be the development of easier movement coordination for the purpose of more successful foraging. The Nautilus shell shape and its mathematical description also aroused Descartes' interest: In 1638, he defined the type of spiral where the angle between the radius and the corresponding tangent is constant, i.e. where the rays follow each other in an increasing geometric series.

According to Dirac, the physical law must also be mathematically beautiful, and according to Leibniz, our world is the best of all worlds.

5.3. About the Human Body and the Proportions of Rectangles

The diversity of the human race has been determined by a series of genetics and historical factors until today. The human body has a very complicated structure: it is made up of hundreds of bones and even more muscles. Consequently, the number of possible ratios is also extremely large. The variety of body types can be traced back mainly to genetic reasons. It would be debatable to proclaim a certain body shape or body proportion as ideal. Still, if we were to examine the proportions of people considered beautiful by the majority, and these proportions were close to the same based on a large enough sampling, we would discover a certain regularity, viz. the mathematical formulation of beauty.

The concept of harmonious body proportions and beauty was already connected with the ancient Greek sculptors, since they created their statues depicting ideal men and women based on certain formulas, but not based on real models. (Figure 10.). Even nowadays, this connection accompanies the positions of many philosophers and artists regarding beauty.

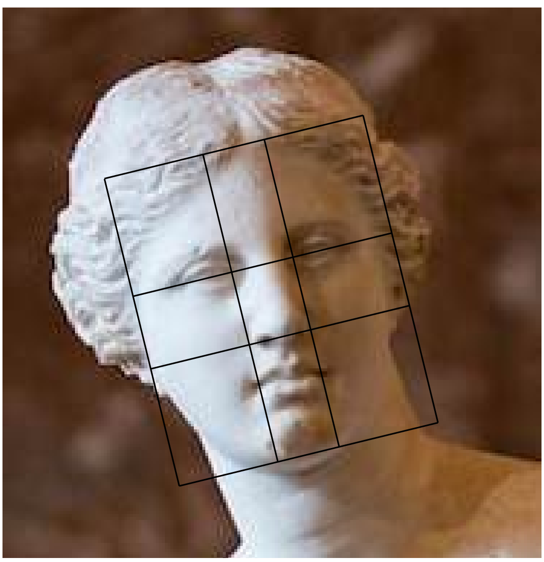


Figure 10. Detail of the head of the Venus of Milo statue. The face in the vertical proportions of the golden ratio: hairy scalp, eye line, tip of the nose, tip of the chin, horizontally (symmetry also applies here): cheekbones, inner corner of the eye, nostrils.

According to Thomas Aquinas: „ Beauty is that which is pleasing to the eye, and beauty is that which is radiant and proportionate.”. Then, in the Renaissance, L. B. Alberti defined it as harmony and beauty proportion: beauty depends on the harmonious arrangement of parts. This connection of proportion and beauty clearly marks the aspiration to define the „most beautiful proportion”. Of course, a mathematical ratio cannot be beautiful in itself, rather it can be called so because of some kind of manifestation. Perhaps it should be sought in such a way that the mentioned ratio takes precedence over other ratios, e.g. when considered from the perspective of practicality, precisely because of its simplicity: „it can be given with fewer instructions”, „it requires less initial data”.

This is true for the golden ratio, as there is no need to specify the ratio, as e.g. 1:2, but applies the relationship of the two parts to the whole. In many cases, nature chooses processes that can be carried out with fewer instructions, but this is in no way proof that the golden ratio can only be the preferred proportion of beauty. The idea that the golden ratio has an aesthetic meaning originates from Zeising (1854), and Fechner in his 1876 experiment aimed at the psychological significance of the „golden ratio”. In Fechner’s experiment, he did not study human body parts, but simple plane figures: rectangles, which also show the ratio of their sides in their appearance. Fechner investigated and summarized which of certain rectangles the experimental subjects find the most attractive (empirical verification).

During the processing of the topic, beauty and its description with proportions in the fine arts captivated the students with a humanistic orientation.

5.4. Rectangle Beauty Contest

Task description: Cut out rectangles from paper, one side of which is 5 cm, and the other 6, 6.5, 7, 7.5, 8.09≈8.1, 8.5, 9! Mark these with letters A, B, C, D, E, F, G! Put it in an envelope, then hand the envelope to your partner and ask him/her to participate in the game, i.e. carefully observe the rectangles and rank them according to their beauty with 1st, 2nd and 3rd place! Try to make judged the rectangles with as many of your friends as possible! Based on the data, calculate the mean and standard deviation, and plot the obtained values on a graph!

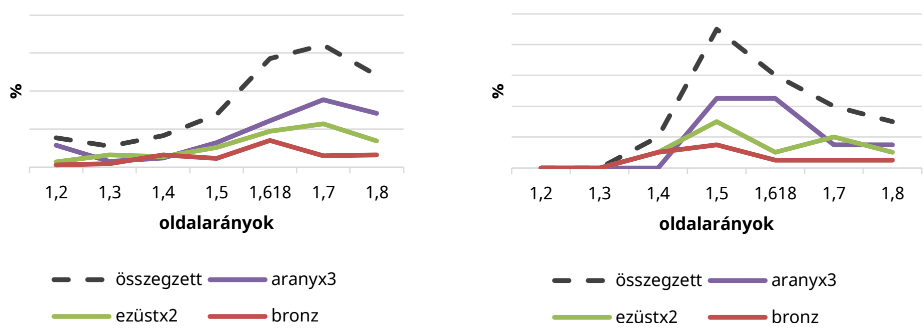


Figure 11. Weighted results of the 375-sample vote on the left and the 8-sample vote on the right.

The students received the „contestants" (rectangles prepared in advance according to the task description) in an envelope, and everyone chose their winners. The envelopes contained plain white rectangles, which were spread out on a dark brown table and arranged by the students to their liking.

At the end of the judging, everyone presented their winners, the data was evaluated and represented in an Excel table (Figure 11.). We also conducted a larger sample survey on the Internet.

5.5. Rectangle Plastic Arts

Task description: Slide two squares of paper on top of each other so that you get the rectangle you like best, then fasten it with a paper clip or adhesive tape! Measure the length of the sides of your rectangle and calculate the ratio of the sides! Calculate the mean and standard deviation of the individually obtained values in the class!

The students made the rectangle they thought was ideal, then measured the sides of the resulting rectangle and calculated their ratio (Figure 12). The values thus obtained were compared with the result of the previous measurement. At the end of the task, everyone made the „perfect rectangle" (they also took their „treasure" home").

Figure 12. By putting two rectangles together, the pupils fix the rectangle they think is ideal.

5.6. Navel Ratio

Task description: We tie a loop to one end of a rubber band so that our feet fit comfortably, and we attach a straight ruler to the other end. The length of the rubber band should be 140 cm. Put your foot in the loop, straighten the tape (it is not necessary to stretch it) and mark it with a felt pen at $140\text{cm}\cdot 0.618 \approx 86.5$ cm from the ground!

Control experiment: stretch the tape to different degrees and measure the ratio of the marked sections (average of 10 measurements, with standard deviation).

Step into the loop, one of your partners will pull the tape up to the top of your head so that the ruler touches it horizontally! Place a pen next to your navel, perpendicular to your belly, and then have another partner measure the difference between the sign of the pen and the tape marking (previously made with a felt-tip pen) with a ruler! (if the line is e.g. 2 cm above the pen, then d=-2cm) (averaged, with standard deviation)

The last task caused the most controversy. The measurement was carried out as described, and the rubber band was carried out with the rubber band available in meter goods stores, as described (Figure 13). The results are very scattered, but actually here we examined the proportions of our body and sought the answer to whether we are perfect according to the golden ratio.

Figure 13. Students examine the coincidence of the dot drawn on the rubber band in the gold section and the navel.

After evaluating the results, we found that although we obtained values close to the golden ratio, we are still not perfect".

5.7. Summary of Practical Experience

Overall, it can be said that the tasks quickly aroused the students' curiosity and a constructive attitude was observed during the work. Based on our experience with the topic and the sessions we have completed, it can be assumed that the adaptation of the topic with a pre-prepared Excel template can be tried out in an average class, as the measurability of beauty easily inspires the students, and the search for answers brings new questions. In this way, the tasks are suitable for arousing students' interest in natural sciences, and their processing also contains interesting possibilities within the framework of the mathematics subject.

The topic also brought with it some practical questions, whether we would get a more attractive shape if we applied the ratio of the golden ratio in the case of buildings? The boys' suggestion is also interesting as to how well, for example, the proportions of the silhouettes would follow the ratio in the case of cars that are generally considered beautiful. Their assumption regarding the questions was that aesthetic beauty can be overwritten and distorted by functionality applied by humans.

When working on the topic, it was suggested that, in addition to rectangles, spatial shapes could be made that contain the divine proportion, i.e. „golden bodies". The golden cube and golden truncated sphere were made with a 3D printer for further surveys (Figure 15).

The relationships valid for the shapes are shown in Figure 14a and Figure 14b:

$$\frac{a}{b} = \frac{b}{c} = \frac{1+\sqrt{5}}{2} \approx 1{,}618$$

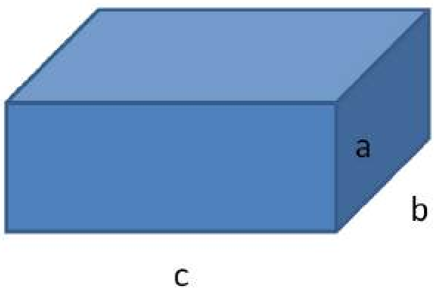


Figure 14a

$$\cos\alpha = \frac{1}{\Phi}$$

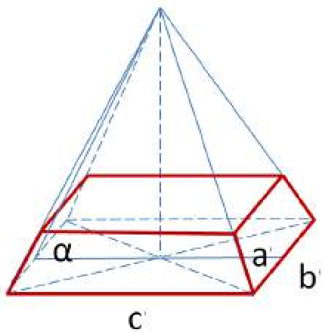


Figure 14b

Figure 15. Gold cubes and gold truncated spheres made with a 3D printer

5.8. pARTicle physics

The particle physics chapter of modern physics deals with the discovery, properties and applications of the micro world, but it is almost incomprehensible to students and ordinary people, since its constituent elements are not visible to the eye, and its size range is typically below 10^(-18) m. Because of this, the teacher also has a very difficult task at school, he/she cannot illustrate the processes, even though in the 21st century, knowledge of subatomic particles is already essential, since the discoveries related to them have been known for several decades. In addition, we are hearing more and more about medical problems that can be solved through the discoveries made by particle physicists. As an example, we can mention the imaging procedures used in medical diagnostics, which are already common nowadays, such as MRI or PET, which make excellent use of how we can perform new types of medical diagnostic tests with positron particles (Bercovich & Javitt, 2018) (Duclos, et al., 2021) [4], or about high-energy protons that are used to cure cancer tumors with so-called hadron therapy (Degiovanni & Amaldi, 2015) [5], but that research is also getting more and more attention when we can use the lepton called muon to illuminate the inside of volcanoes, pyramids, and caves, often preventing an unnecessary excavation (Olah, et al., 2023) (Hamar, et al., 2022).

The Standard Model of particle physics (Cottingham & Greenwood, 2007) is the theory describing fundamental interactions and elementary particles. The experiments so far have confirmed the physicists' previous predictions. Similar to Mendeleev's periodic table in Figure 16 the visible Standard Model table summarizes the already known particles in a clear and orderly manner.

Figure 16. Standard Model of particle physics [6]

5.9. Quark Cubes

We wrote about it earlier that the most difficult thing in this topic is that we want to get a glimpse into the mysteries of an invisible micro world, to understand the processes taking place there. In order to make it easier to understand, an educational aid was developed in Hungary, which was designed for the particle physics chapter within the physics subject, but is also closely related to several other topics, scientific fields, and subjects (Oláh, 2016). We have already mentioned that since the 1960s we have known what makes up protons and neutrons, but in chemistry classes, when students learn about the internal structure of the atom, they only get to the level of nucleons. In the 21st century, not only in physics classes, but also in chemistry classes, it would be mandatory to talk about the fact that protons and neutrons are not elementary particles, since they have an internal structure. A very imaginative and perseptive way to demonstrate this is to model the particles with paper or wooden blocks. As a first step, when the children make the cube set, their dexterity develops to a great extent, a similar task could even occur in technology classes. For students, it also presents the laws of quantum color dynamics at a high level, which occur during university studies, in a very simple way, with the analogy of additive color mixing, which may also be needed in drawing and art classes during drawing and painting. This would be an opportunity to draw students' attention to the fact that there are two types of color mixing. While the quantum color dynamics describing the properties of particles can be described by the laws of additive color mixing, the mixing of paint in art classes follows the rules of subtractive color mixing. Although it seems simple, the experience is that the students (in fact, often even the teachers) cannot make a hexahedron out of paper, so it is a good practice opportunity, and it is also helpful for the spatial geometry topic in the mathematics subject, if the students learn how to draw solid meshes (Vass, 2010) (Oláh, 2016).

By making and using quark cubes, we increase our understanding of the processes taking place in the micro world through independent, active learning. In particle physics, physicists everywhere classify particles into groups of three, but actually six is the magic number, since we know six quarks, anti-quarks, leptons or anti-leptons. It was therefore obvious to make a cube, on all six sides of which different concepts can be displayed, and with these playful tasks we can learn about the basic chapters of particle physics that can be taught even in high school. The most important thing is actually the game, creativity and the so-called „Hands-on mind-on" method, according to which the students not only learn theoretically, but also become a creative part of the process, so the concepts, relationships are more deeply embedded during the longer time involved in making them.

In the majority of physics laboratories, you can find expensive experimental devices sold by companies that manufacture teaching aids, which are mostly only suitable for presentation by the teacher. On the other hand, the practice proves that the students like the experimental tools and objects they made much more. Making a cube set is very easy and has low budget. All we need are colored cardboard papers, Styrofoam filler, scissors, glue, paint and felt-tip pens. In Figure17, Figure 18 and Figure 19 you can see the students preparing the model set consisting of a lot of elements.

Figure 17. Quark cubes under preparation

Figure 18. The cube templates can also be made using a computer

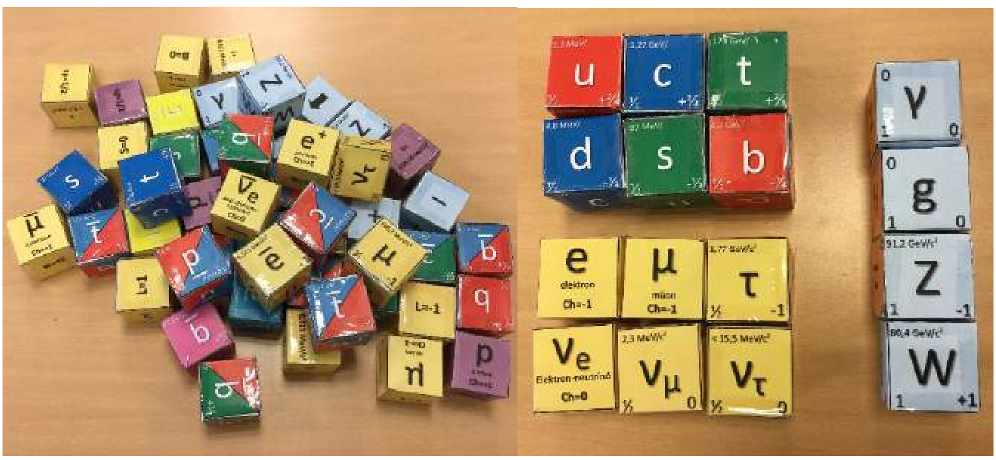


Figure 19. Quark cubes and the Standard Model laid out of them

First of all, the concept of „atomic = indivisible" stated by Democritus should be dispelled with the help of model blocks, and the fact that protons and neutrons are not elementary particles, as is still stated in several textbooks (Furley, 1987). Elemi Under elementary particle we mean that it has no internal structure and cannot be broken down into smaller components. The RGB (red, green, blue) cubes will be the valence quarks that make up the nucleons, the initial letters corresponding to their English names are written on the sides. The styrofoam „maggots" model the mediator particles of the strong interaction that hold together nucleons of the same charge and also act between quarks, essentially like a super glue. As for why our cubes are the colors they are, it is enough to mention the basic connections for the students. Quantum color dynamics is a very difficult chapter, higher level mathematical knowledge would be needed to understand it, so in high school it is enough to record only the simplest rules. In nature, there is only a white hadron, which can be produced from three basic colors or two colors, but then one color must be paired with the particle's own anticolor. For this, we can use the analogy of additive color mixing learned in optics. For another, later task, in addition to the already indicated quark flavors, we also write the electric (fractional) charges of the quarks on the cubes. We formulate another „rule", according to which if a particle consists of three quarks, it is called a baryon, and if it consists of one quark and one anti-quark, it is called a meson. As a next step, the color charge must also be taken into account, since the Pauli principle must also be fulfilled here. According to this, two particles cannot be in the same quantum state, and if the quantum numbers do match, they must at least differ in their color charge. During group, active tasks, students learn the names and meanings of these difficult, unusual concepts much more easily by playing. After learning the electric charge of quarks, determining the electric charge of baryons and mesons can be another interesting task. But we can even gain an insight into the world of mystical antimatter by explaining the concept of antiparticle with the help of cubes. Then special, so-called antiquark cubes are made and used for modeling (Katona, 1978).

5.10. Gastro particle physics

The knowledge of particle physics based on an abstract mathematical formalism can also be served in a „digestible form" for interested students. We can even arouse our students' interest in the processes taking place in the microcosm with gastronomic creations. Again, with the help of STEAM pedagogical methods, we try to approach the abstract, hard-to-understand knowledge of particle physics. Why not bring the topic closer to the students with a playful and at the same time tasty project? In a way that has been tested and enjoyed great success in several cases, the invisible particles of the micro world can be modeled not only with paper cubes, but also by making for example hadrons from sweet, edible ingredients. For this gastronomic as well as art project, the participants can put together muffins (cupcakes), which they eat together at the end of the learning process. Here, too, active learning, attitude formation, perceptiveness and creativity play an important role. On the hadron muffins shown in Figure 20, in addition to the correctly chosen types of the flavors of the quarks, the color-anti-color combinations of the particles of the strong interaction that hold them together, the gluons, are also appropriate.

Figure 20. The produced hadrons being edible with quarks and gluons.

Summary

In a first approach, STEAM pedagogy is a creative, innovative and pragmatic methodology that provides an effective and efficient answer to the challenges of the VUCA world and the economy being rich in knowledge. It changes the culture of design, development and evaluation. Its fundamental characteristic is trans-disciplinarity, which prioritizes the complex, structured, collaborative, student- and learning-centered planning approach, in contrast to the previous curriculum-centered, subject-fragmented practice. Competence-based development in general, but in the case of STEAM pedagogy in particular, focuses on action learning. In terms of practical examples of STEAM pedagogy, it mainly focuses on the development of problem-based, project-based and inquiry-based learning, and strengthens student and, last but not least, teacher creativity. In a second approach, STEAM pedagogy is a mindset that determines the entire learning-teaching process, thus having a significant impact on internal motivation and student and teacher attitudes. This approach supports the fact that STEAM pedagogy is truly institutionalized, i.e. its implementation should not be a fragmented innovation, but a significant part of the organizational culture. Thus, the complexity and transversality analyzed in our study have a good chance of being realized in the practice of pedagogy. The presented good practices (music physics, golden section, particle physics) are examples of methodology, approach and institutionalization of STEAM pedagogy.

The practical examples raise many questions and dilemmas. How can the above practical examples of STEAM pedagogy, which are basically based on the student's interest, curiosity, motivation and, last but not least, creativity, be implemented in a teacher- and teaching-centered education system? Why is it important for STEAM pedagogy to be an approach priority and not just a methodological innovation within an educational institution? How can teachers' cooperation, attitudes and motivation be strengthened with regard to the implementation of STEAM pedagogy?

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