Integrating 3D Modelling into STEAM Education

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Abstract: *3D printers appear at all types of schools more and more frequently. To exploit them effectively, educators must become familiar with their appropriate application in courses. The authors participate in an international ERASMUS+ project that intends to assist future (pre-service) teachers in planning and carrying out their future teaching activities with 3D modelling through a STEAM-based transdisciplinary approach.*
The main aim of our project is to design, develop, and implement appropriate teaching and learning practices using 3D modelling. In order to follow contemporary trends in education, we prefer and promote the learning-to-learn approach based on "learning to do" tasks. They address 3D modelling in order to enhance learners' creativity. To enhance our students' motivation, we invite them to design and develop subjects for their needs.
A MOOC is a part of the project to support both teacher training and school-based STEAM learning. It aims to facilitate instant and worldwide access to STEAM learning. In particular, we pay attention to and respect the specifics of partner countries' curricula and teacher training. The tasks and activities address both in-class and online courses for future teachers. Our paper contains selected examples.
As our long-term aim is to concentrate on transdisciplinary education, we develop not only these activities. Moreover, we create a repository of high-quality teaching and learning resources as well as their evaluation criteria. The dissemination of project results is also premeditated.

1. Introduction

Today's fast technological advancement and constantly changing market needs result in pressing calls for flexible education systems that can provide students with the skills needed to succeed in the uncertain world they face. The progress in Science, Technology, Engineering, Arts, and Mathematics is remarkable and must be reflected in the preparation of people for their jobs. STEAM education is accepted as a correct response to these challenges [1]. Leavy et al. [2] demonstrate the extensive growth of STEAM-based educational approaches and cases. The introduction of relevant content into classrooms must be quick but stepwise, long-lasting, and reflect incoming trends.

One can learn from the current situation in Information Science and its business applications. Cedefop's EU skills forecasting model indicates that about 87% of all EU jobs needed at least a basic digital skills level in 2021 [3]. During the same period, the demand for specific skills grows even faster: GreyViews [4] predicts the growth of the 3D printing industry from 11,5 billion USD in 2020 to 47,5 billion USD in 2028. One can estimate an analog expansion of jobs requiring 3D-related printing knowledge and skills.

Schools and universities have to react to these challenges as soon as possible. The authors have extensive experience introducing innovative content related to programming and information sciences during their careers.

The appearance of programming languages resulted in mini-languages [5]. The introduction of spreadsheets resulted into their incorporation into relevant courses [6].

Often, the initiative comes from departments of Mathematics because various advanced information science courses exploit mathematics as their background [7]. Recently, Artificial Intelligence has served as an example of course innovation [8].

This trend is unstoppable. The current booming onset of 3D printers has resulted in their more and more frequent appearance in all types of schools. To exploit them effectively, educators must become familiar with their appropriate application in classes. The authors are members of an international team collaborating on an ERASMUS+ project which assists future (pre-service) teachers in planning and carrying out teaching activities with 3D modelling through a STEAM-based transdisciplinary approach. Thus, our global aim is to design and develop university teacher training courses that facilitate the 3D modelling skills of pre-service teachers with various technologies and to reach a wider audience and students through such approaches. In addition, they support teacher training in the participating countries and beyond.

Complex solutions require:

- To design, develop, and implement teaching approaches with 3D modelling involving a variety of technologies and STEAM-based transdisciplinary approaches for future teachers;
- To promote the learning-to-learn approach by "learning to do" tasks enhancing creativity and production of 3D models among learners;
- To develop a MOOC to support both teacher training and school-based STEAM learning;
- To facilitate direct access to 3D technology for all interested;
- To support international cooperation in integrating STEAM approaches into their curricula and teacher training.

To achieve optimum results, we have aimed to motivate particular groups of students and be attractive to them and their neighborhoods [9]. In our project, we develop tasks and activities for both in-class and online courses for future teachers related to 3D modelling and STEAM-based transdisciplinary education, exploiting as much from the existing curricula as possible. Then, we evaluate all project activities and resources, train pre-service teachers in each participating country, create a repository of high-quality teaching and learning resources, develop a MOOC for 3D modelling teacher education, and disseminate project results to a wider audience promoting 3D modelling and STEAM education. Finally, we plan to generalize our experiences and formulate a series of proposals for all levels of the educational hierarchy.

In our presentation, we will exemplify the issues and present our solutions.

2. STEAM Education as a Complex Task

In general, the suggested approach to changes in education consists of four stages [10]: First, the constellation of forces leading to the development of 3D-printing-based education is discussed. Second, its state-of-the-art and potential links to educational content are discussed. Third, the appropriate elements of 3D-modelling and printing are incorporated into courses in a way that will depart substantially from patterns characteristic of traditional education. Fourth, the implications for educators, educational researchers, policymakers, and educators are specified.

In the paper, we concentrate on the first two stages: finding optimal areas for introducing 3D modelling and printing in the current curricula and then to enriching them with relevant practical exercises. Simultaneously, exploiting 3D allows us to produce real-life objects and, as such, to enhance the visual side of learning and demonstrate links between theoretical aspects of study content and its application. This means that 3D printers give us a unique opportunity to integrate STEAM approaches and comprehend intricate relationships among individual courses.

At the same time, the course developers are supposed to possess identical qualities, i.e., to make the complexity understandable. That is why our educational strategy begins with the "direct and instant" application of 3D modelling and printing. Below, cross sections of solids serve as an example: the theoretical backgrounds are part of the geometry course; the only novelty is their transfer to the instructions for the printers.

Then, the students are given more freedom. In a stepwise manner, they should proceed to implement their ideas and knowledge to formulate more complex tasks, find their solutions, and come up with their outcomes. From a didactical point of view, this is the most difficult part of the transfer. The team members exploit their previous experience with designing and implementing problems, demonstrating the relationships between Mathematics and its four partners: S, T, E, and A. In our interpretation, the letter E in STEAM stands for Engineering and Economics because students' financial literacy also belongs to our goals.

Therefore, the project is built on the authors' previous experiences with active learning such as:

- Alternative solutions to the same problem [11] by exploring different approaches to solving the same mathematical problem and their contribution to students' understanding and fostering creativity.
- Brute-force solutions [12] demonstrating the application of brute-force methods combined with IT tools to tackle complex mathematical challenges, enhancing students' problem-solving skills.
- Exploitation of spreadsheets for finding large sets of solutions [13] showed how spreadsheets can be effectively used to explore multiple solutions to mathematical problems, thereby integrating computational thinking into the learning process.
- Teaching Mathematics as a managerial task [14], where the management analogy was used to make mathematics more engaging for students, emphasizing the role of organizational skills in education.
- Recognizing non-explicit knowledge in Mathematics [15] focused on how implicit knowledge in mathematics can be recognized and managed to improve educational outcomes.
- Integrating Augmented Reality in Constructional Geometry Lectures [16] explored the use of augmented reality to enhance the teaching of constructional geometry, providing students with a more interactive and immersive learning experience.
- Adapting Geometry Education During the Pandemic [17] by discussing the challenges and solutions for teaching geometry in a remote learning environment, with a focus on maintaining educational quality during the pandemic.
- Creating tools in GeoGebra software [18] and highlighting the development of custom tools within GeoGebra to facilitate the teaching and learning of complex mathematical concepts, supporting the integration of technology into the classroom.
- Utilizing GeoGebra tools for Teaching Monge Projection [19], which focused on the application of GeoGebra in this essential topic in descriptive geometry.
- Developing educational materials for the Monge projection using GeoGebra [20] aims to improve students' understanding through interactive and dynamic materials.

Usually, when discussing mathematical problem solving, Mathematics is primarily connected with one application area, i.e., the relationship "Mathematics: Application Area" can be described as 1:1. The main task of our research project will be to design problems with 1:M or M:N relationships, i.e., to solve problems which require not only application of mathematics but also various interconnections among activities which (formally) belong to different fields of knowledge and are taught in different subjects. An example of such a complex relationship, its formulation, and its solution is described in our paper [21].

3. Trends in teaching Mathematics in Czechia and Slovakia

Mathematics education in the Czech Republic and the Slovak Republic is designed to be comprehensive and interconnected with other areas of study, particularly within the STEAM (Science, Technology, Engineering, Arts, and Mathematics) framework. Mathematics teaching places a significant emphasis on interdisciplinary links, ensuring that students can see the relevance of mathematical concepts in various contexts and subjects. Recent revisions in the educational framework also highlight the importance of digitalization, incorporating modern technologies such as 3D printing to enhance the learning experience and develop students' digital competencies.

3.1. Basic Principles of Mathematics Education

1. *Development of Mathematical Literacy:* Mathematics education aims to develop students' ability to understand and use mathematical concepts and skills in everyday life; it includes solving mathematical problems and the ability to think logically, reason, and work with data.
2. *Progressive Complexity:* Mathematics education is structured to be gradual and adapted to the age and abilities of the students. In primary school, it starts with simple arithmetic operations and gradually progresses to more complex topics such as algebra, geometry, and statistics in secondary school.
3. *Application and Interactivity:* Mathematics is not taught solely theoretically; there is an emphasis on practical applications and interactive teaching methods. They include using modern technologies, group work, and projects that connect mathematics with the real world.
4. *Individual Approach:* Given students' different abilities and needs, an individual approach is important; it includes differentiated instruction and support for students with difficulties and gifted students.

3.2. Curicullum Documents

Several key documents govern mathematics education. The main curriculum document is the Framework Educational Program (RVP), which sets the educational goals, content, and outcomes for different school levels. For primary and secondary schools, specific programs are RVP ZV (for primary education) and RVP G (for grammar schools), detailing the expected outcomes and curriculum for mathematics. Based on the RVP, each school creates its own School Educational Program (ŠVP), which concretizes and adapts the educational content to the needs and conditions of the school. The ŠVP provides a detailed description of how mathematics education will be implemented in a specific school.

Additionally, the ministries of education issue various methodological guidelines and recommendations that offer teachers support and instructions for effective mathematics teaching. These documents may include recommendations for using modern technologies in education or working with heterogeneous student groups. The primary sources of information on educational programs and methodological guidelines are the official websites of the MŠMT and the National Pedagogical Institute of the Czech Republic, where these documents are publicly available.

In the next sections, we describe how 3D modelling and printing can contribute to fulfilling these aims.

3.3. Individual Assignments: Using 3D Printing in Geometry Education – Activity on Cross Sections of Solids

Three-dimensional geometry is rich in problems that can be "completed" using 3D printing. These problems mostly belong to the 1:1 category, as specified above, because no other school subject needs to be involved for their complete solution. Such tasks can be done individually or by pairs of learners because they test narrow knowledge: mathematics and 3D printing skills.

Teaching the concept of cross sections of solids can be challenging, as students often struggle to visualize and understand 3D objects and what a planar section of these objects means. Traditionally, this topic begins with simple sketches of a cube in a notebook using free parallel projection to represent a 3D object on a 2D plane. However, this method can leave students without a clear understanding of the 3D object and the practical implications of a planar section.

To enhance students' comprehension of cross sections of solids, we implemented an innovative activity using 3D modelling and printing to provide a hands-on, interactive learning experience. This pilot study was conducted during the winter term of the 2023/2024 academic year, involving seventeen second-year bachelor's degree students specializing in teaching for the second grade of elementary schools at the University of Ostrava.

The activity began with an introduction to 3D modelling, where students were guided through creating a solid, such as a cube, using GeoGebra 3D software. Each student ensured their model was accurate and then exported it as a .stl file for further processing. This initial step aimed to bridge the gap between theoretical understanding and practical visualization, as students often find it challenging to conceptualize 3D objects from 2D drawings.

Following the modelling phase, students were introduced to the PrusaSlicer software. They learned how to import their .stl files into PrusaSlicer and slice the solid with a plane. This step allowed students to set the slicing plane at any angle and position, making it simple to adjust the plane and observe the resulting cross sections. The ease of this process, requiring just a few clicks, encouraged students' motivation to explore and experiment.

After preparing the sliced models, students exported the files as .gcode and printed them using a 3D printer. This hands-on approach enabled students to physically observe and manipulate the sliced solids, providing a tangible understanding of how a plane intersects a 3D object. By manipulating the printed sliced models of the cube, students can discover basic principles that will later help them solve tasks in parallel projection. For example, they will understand that the intersection of two parallel planes with a third plane that is not parallel to them is the intersection of two parallel lines. This experiential learning method significantly enhanced their spatial reasoning and visualization skills.

Students worked in pairs to further deepen their understanding and explore different slicing angles and positions. They were provided with research questions to guide their exploration, such as determining the shapes that may result from slicing a cube with a plane, creating slices that form regular polygons, and identifying special cases. Through practical experimentation, students discovered that slicing a cube could result in various polygons, including triangles, quadrilaterals, pentagons, and hexagons. They documented their findings and shared their results with the class, fostering collaborative learning and discussion.

This activity aligns with the STEAM approach by integrating technology and engineering principles with traditional mathematics education. 3D modelling software and 3D printing technology encourage students to engage in engineering design processes, fostering creativity and problem-solving skills [22]. By incorporating artistic elements in the design and visualization of geometric shapes, the activity also touches on the art component of STEAM, promoting a holistic understanding of complex concepts [23].

The benefits of this activity extend beyond understanding cross sections. It supports students in grasping geometric relationships and spatial configurations, which are essential for solving positional tasks in space [24]. It also improves their comprehension of 3D objects' representation in 2D, which is fundamental for fields such as engineering, architecture, and computer graphics [25]. Furthermore, developing spatial reasoning and visualization skills is critical for success in STEM fields and is linked to enhanced problem-solving abilities and academic performance in mathematics and science [26].

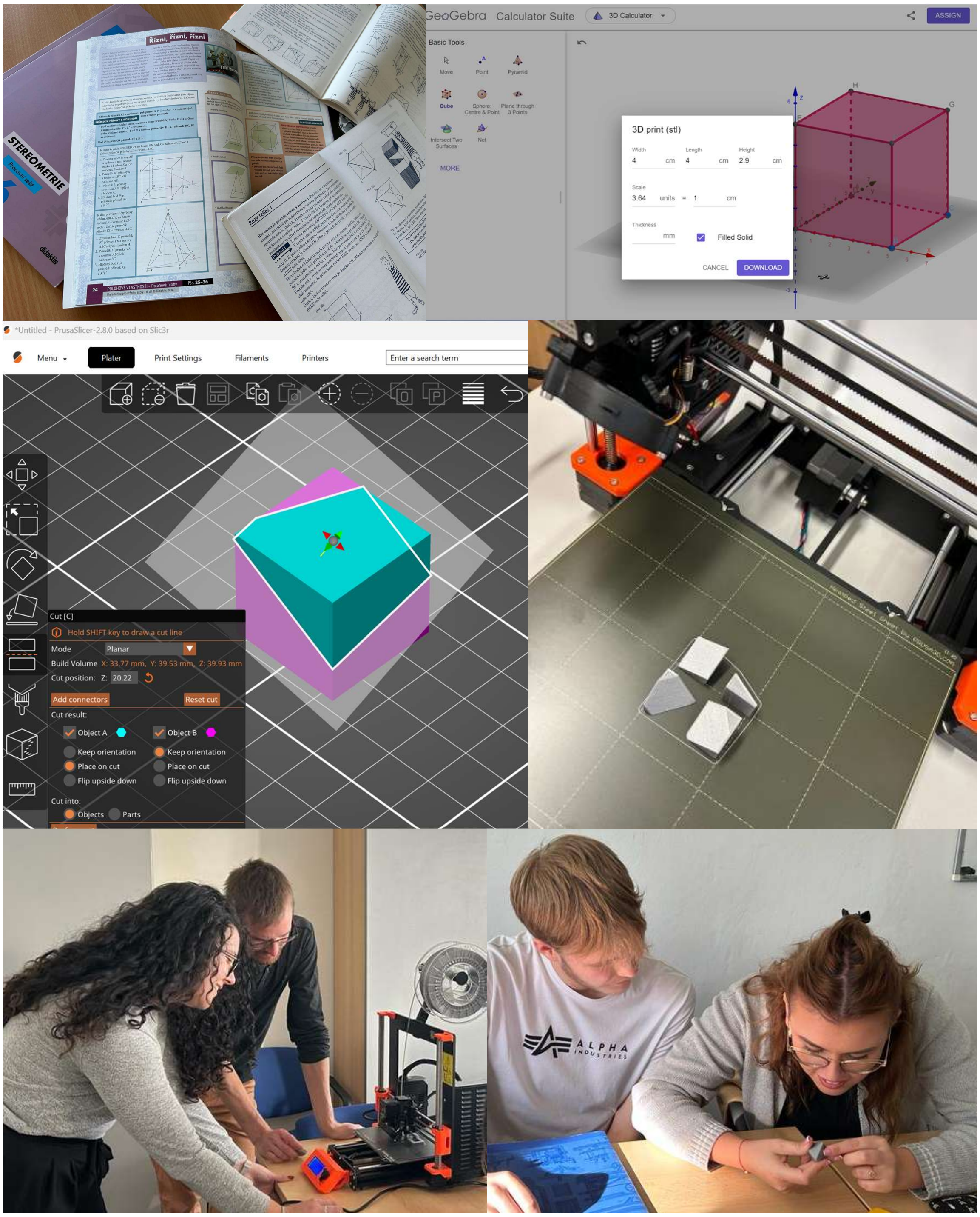

Figure 1 3D modelling and printing activities on Cross Sections of Solids

3.4. Assignments for Pairs: Creative Tangram Design Using 3D Printing in Geometry Education

Tangram is an ancient Chinese puzzle with seven geometric shapes known as "tans." These shapes – triangles, squares, and parallelograms – can be arranged into various patterns and images. Using Tangrams in education has been widely recognized for its ability to develop spatial imagination, geometric reasoning, and creative problem-solving skills. Research has shown that working with Tangram pieces helps students improve their understanding of geometric shapes, relationships, and patterns while also fostering their ability to solve geometric problems through hands-on activities [27].

In the field of geometry education, Tangrams are a valuable tool for teaching geometric transformations and helping students discover the relationships between polygons. By manipulating the pieces, students enhance their logical thinking and strengthen their understanding of geometric concepts [28].

In this activity designed for future mathematics teachers, students are tasked with creating their own variation of a Tangram puzzle using TinkerCAD software and 3D printing technology. This process combines creativity with technology, allowing students to gain experience in 3D modelling while also developing their digital competencies [29]. Students begin by designing unique Tangrams in shapes such as hearts, eggs, or other creative forms. TinkerCAD, an intuitive software, enables students to model various polygonal shapes that can later serve as educational tools in their teaching practice.

After completing the design, students export their models as .stl files and prepare them for 3D printing using PrusaSlicer software. This hands-on approach allows students to experience the full process from design to final realization. Once the models are printed, students can work in pairs, exchanging Tangrams and attempting to assemble the provided puzzle, or they may collaborate from the very beginning by jointly designing their Tangram. This approach promotes early-stage teamwork, encouraging idea-sharing and cooperative problem-solving, which enhances collaboration, analytical thinking, and creativity throughout the process.

We suggest using this activity as a motivational task before beginning lessons on planimetry. When students assemble Tangram puzzles, they engage with various types of polygons in a fun and interactive way. They can explore metrical relationships, such as internal angle measurements and positional relationships, by connecting different types of polygons to form larger shapes. The complexity of the task can be gradually increased, for example, by asking students to create Tangrams in the shape of a heart or an egg, where part of the polygon transforms into a circular sector.

An important aspect of this activity is its alignment with the STEAM approach. By integrating creativity, technology, and geometry, this activity encourages students to engage in artistic design while solving mathematical problems. 3D printing technology fosters engineering skills, while the Tangram pieces' design and assembly engage students in scientific inquiry and creative exploration. This interdisciplinary approach promotes a holistic understanding of complex concepts, helping students see the connections between different fields of study. The focus on hands-on learning, problem-solving, and creative expression makes this activity an excellent example of the STEAM framework in action.

The intuitive connection between 2D and 3D space is another essential aspect of this activity. While modelling, students work with different types of polygons in a 3D environment, such as polyhedra (prisms with polygonal bases). This process gives them practical experience that enhances their understanding of more complex geometric concepts, preparing them for applying these skills in their future teaching practice.

This activity not only encourages creative problem-solving but also supports the development of digital literacy and geometric thinking – key skills for modern mathematics teachers. Using 3D printing and modelling in creating Tangrams allows students to better understand the relationship between 2D and 3D space while deepening their geometric knowledge and skills. By aligning with the STEAM approach, the activity allows students to integrate creative design, technological tools, and mathematical reasoning, making it an effective and engaging educational strategy. This approach is suitable for implementation at various educational levels, where students can discover new geometric concepts through hands-on exploration.

3.5. Group Assignments: 3D Modelling and Printing – a Base for Collaboration

Contemporary educational methodologies underline the need for multifaceted tasks that an individual can hardly complete. 3D modelling and printing offer an excellent solution for such problems. In the above mathematical problems, the printouts have been directly specified by their mathematical properties. At the same time, real-life objects are rarely regular, and formulas do not define their shapes. As a result, several specialists must be invited to complete them, and the solution is made in stages [21].

Our example task is to create medals for a large school sports competition. First, it is transformed into a group project. The student team(s) are asked to resolve it using 3D printers. The medal's look and size are exclusively upon the group's decision. The outcome requires role distribution, planning, and collaboration. At least five roles have to be established: Mathematician (all needed numerical calculations), Scientist (selection of material with required qualities), Economist (financial planning and cost calculations), Artist (design of medals), Engineer (3D printing).

There is an optional plan of work:

i. The manager must learn the number of medals and other requirements of event organizers.
ii. The medal designer then prepares and proposes several sketches for approval by the sports event's organizing committee.
iii. The technologist analyzes the feasibility of producing the selected pattern and specifies the most appropriate material, medal dimensions, weight, durability, and other technology factors.
iv. They choose the filament and its amount for each of the three medal types, and the manager must ensure its delivery.
v. The medal design is transformed to be prepared for 3D printing.
vi. The first samples are shown as the pattern to the organizers for final approval. After their consent, the requested number of medals is printed out.

Task division is part of the problem solution and should be done by the students. Notice that the mathematician is not directly mentioned in any of the above subtasks. Nevertheless, without him/her, the whole problem would not be solvable.

4. Conclusion

The above examples of individual, pair, and group tasks indicate a high potential for 3D modelling and printing in education. These experiments were done at the university level, but other experiences indicate that STEM-oriented teaching can be successfully completed at elementary schools, too [30].

Our observations, as well as positive feedback from the questionnaires, suggest that actively incorporating 3D modelling and printing into the classroom increased student motivation and engagement in exploring spatial relationships. This practical experience of solving real problems in a tangible space prevented potential misunderstandings in the interpretation of 3D objects, which are often represented in 2D tasks. Thanks to the printed models of positional problems, students could verify their existing theoretical knowledge while also discovering new concepts. Using tools such as GeoGebra, TinkerCAD, and PrusaSlicer, they could increase their digital competence, deepen their understanding of geometric relationships, and improve their spatial imagination and reasoning. Such an approach, rooted in the STEAM framework, proved beneficial in fostering creativity, problem-solving skills, and collaborative learning, indicating its wider applicability in other fields of education.

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References

[1] Lavicza, Z., Weinhandl, R., Prodromou, T., Anđić, B., Lieban, D., Hohenwarter, M., Fenyvesi, K., Brownell, C., Diego-Mantecón, J. M. (2022). *Developing and evaluating educational innovations for STEAM education in rapidly changing digital technology environments.* Sustainability, 14(12), 7237. https://doi.org/10.3390/su14127237

[2] Leavy, A., Dick, L., Meletiou-Mavrotheris, M., Paparistodemou, E., Stylianou, E. (2023). *The prevalence and use of emerging technologies in STEAM education: A systematic review of the literature.* Journal of Computer Assisted Learning, 39(4), 1061-1082. https://doi.org/10.1111/jcal.12806

[3] Skills and changing societies | CEDEFOP (europa.eu) Skills and changing societies | CEDEFOP (europa.eu)

[4] 3D Printing Market Size & Developments Till 2028 (greyviews.com) 3D Printing Market Size & Developments Till 2028 (greyviews.com)

[5] Brusilovsky, P., Calabrese, E., Hvorecky, J., Kouchnirenko, A., Miller, P. (1997). *Mini-languages: a way to learn programming principles.* Education and Information Technologies, 2, 65–83. https://doi.org/10.1023/A:1018636507883

[6] Hvorecky, J., Trencansky, I. (1998). Recursive Computations in Spreadsheets. In: *Proceedings of the Third Asian Technology Conference in Mathematics.* Springer, Tokyo (pp. 290-298).

[7] Su, S. Y. W., Guo, M., Lam, H. (1993). *Association algebra: A mathematical foundation for object-oriented databases.* IEEE transactions on knowledge and data engineering, 5(5), 775-798. https://doi.org/10.1109/69.243509

[8] Ng, D. T. K., Lee, M., Tan, R. J. Y., Hu, X., Downie, J. S., Chu, S. K. W. (2023). *A review of AI teaching and learning from 2000 to 2020.* Education and Information Technologies, 28(7), 8445-8501. https://doi.org/10.1007/s10639-022-11491-w

[9] Al-Mahasneh, R. (2018). *The Role of Teachers in Establishing an Attractive Environment to Develop the Creative Thinking among Basic Stage Students in the Schools of Tafilah Governorate According to Their Own Perspective.* Journal of Curriculum and Teaching, 7(1), 206-221. https://doi.org/10.5430/jct.v7n1p206

[10] Natriello, G. (2005). *Modest Changes, Revolutionary Possibilities: Distance Learning and the Future of Education.* Teachers College Record, 107(8), 1885-1904. https://doi.org/10.1111/j.1467-9620.2005.00545.x

[11] Lovászová, G., Hvorecký, J. (2002). When There is More Ways to Get There. In: Yang, W.-Ch., Chu, S.-Ch., Karian, Z., Fitz-Gerald, G. (eds) *Proceedings of the Seventh Asian Technology Conference in Mathematics,* vol 20002. ATCM, Melakka (pp. 263-272).

[12] Hvorecký, J., Korenova, L., Barot, T. (2022). Combining Brute Force and IT to Solve Difficult Problems. In: *Proceedings of the 27th Asian Technology Conference in Mathematics.* ATCM (pp. 302-312).

[13] Lovászová, G., Hvorecký, J. (2003). *On Programming and Spreadsheet Calculations.* Spreadsheets in Education, 1(1), 44-51.

[14] Hvorecký, J. (2010). *Using a Managerial Analogy for Making Mathematics More Attractive.* Acta Didactica Napocensia, 3(2), 49-58.

[15] Hvorecký, J., Šimúth, J., Lichardus, B. (2013). *Managing Rational and Not-Fully-Rational Knowledge.* Acta Polytechnica Hungarica, 10(2), 121-132.

[16] Ferdiánová, V., Poruba, J. (2020). Augmented Reality in Lecture on Constructional Geometry. In: *APLIMAT 2020 Proceedings: 19th Conference on Applied Mathematics.* Spektrum STU Bratislava, Bratislava (pp. 408-417). ISBN 978-80-227-4983-1.

[17] Ferdianová, V., Gunčaga, J., Ashimov, Y. (2022). Some Aspects of Geometry Education during the Pandemic Situation. In: *EDULEARN22 Proceedings: 14th International Conference on Education and New Learning Technologies.* IATED, Palma (pp. 8284-8291). ISBN 978-84-09-42484-9.

[18] Ferdiánová, V., Poruba, J. (2021). Creation of Tools in GeoGebra Software. In: *Summer school of GeoGebra.*

[19] Poruba, J., Ferdiánová, V. (2019). GeoGebra nástroje pro výuku Mongeova promítání. In: *Sborník příspěvků 9. konference Užití počítačů ve výuce matematiky.* Jihočeská univerzita v Českých Budějovicích, České Budějovice (pp. 17-25.) ISBN 978-80-7394-795-8.

[20] Ferdiánová, V., Poruba, J., Procházková, M. (2021). Geogebra Tools in Creating Materials for Teaching Monge Projection. In: *EDULEARN21 Proceedings: 13th International Conference on Education and New Learning Technologies.* IATED (pp. 5669-5678). ISBN 978-84-09-31267-2.

[21] Hvorecký, J., Schmid, A. (2023). Developing Prerequisite Knowledge for 3D Modelling and 3D Printing. In: *2023 21st International Conference on Emerging eLearning Technologies and Applications (ICETA).* IEEE, Stary Smokovec (pp. 220-224). doi: 10.1109/ICETA61311.2023.10344311

[22] Yakman, G., Lee, H. (2012). *Exploring the exemplary STEAM education in the US as a practical educational framework for Korea.* Journal of the Korean Association for Science Education, 32(6), 1072-1086. https://doi.org/10.14697/JKASE.2012.32.6.1072

[23] Bequette, J. W., Bequette, M. B. (2012). A Place for Art and Design Education in the STEM Conversation. *Art Education*, *65*(2), 40–47. https://doi.org/10.1080/00043125.2012.11519167

[24] Jones, K. (2003). Issues in the teaching and learning of geometry. In: *Aspects of teaching secondary mathematics.* Routledge (pp. 137-155).

[25] Presmeg, N. (2006). Research on visualization in learning and teaching mathematics: Emergence from psychology. In: *Handbook of research on the psychology of mathematics education.* Brill (pp. 205-235). https://doi.org/10.1163/9789087901127_009

[26] Uttal, D. H., Cohen, C. A. (2012). Spatial thinking and STEM education: When, why, and how? In: *Psychology of learning and motivation*, vol 57. Academic Press (pp. 147-181). https://doi.org/10.1016/B978-0-12-394293-7.00004-2

[27] Bohning, G., Althouse, J.K. (1997). *Using tangrams to teach geometry to young children*. Early Childhood Education Journal, 24, 239–242. https://doi.org/10.1007/BF02354839

[28] Sunzuma, G., Maharaj, A. (2019). *In-service teachers' geometry content knowledge: Implications for how geometry is taught in teacher training institutions.* International Electronic Journal of Mathematics Education, 14(3), 633-646. https://doi.org/10.29333/iejme/5776

[29] Tejera, M., Ortiz-Laso, Z., Ulbrich, E., Lavicza, Z. (2024). 3D modelling and printing in mathematics education: Enhancing preservice teachers' knowledge through task design. In: *Proceedings of the 17th ERME Topic Conference MEDA4.* Bari (pp. 452-453). ISBN 978-88-6629-080-3.

[30] Guncaga, J., Korenova, L., Záhorec, J., Ostradicky, P. (2024). *Innovative Approach on Teaching and Learning with Technical Aids for STEM Education at the Primary Level.* Education Sciences, 14(7), 682. https://doi.org/10.3390/educsci14070682