

Using 3D Pens for Creating Personalized Tactile Learning Models for Students with Visual Impairments

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Abstract. Access to tactile learning materials is essential for students with visual impairments; however, such materials are often costly, inflexible, or require advanced technical skills to produce. This paper explores the use of 3D pens as an innovative, low-cost, and teacher-friendly assistive tools for creating personalized tactile learning models in educational settings, and their preliminary evaluation in the context of education of visually impaired pupils. The proposed approach emphasizes accessibility, rapid customization, and minimal digital skill requirements.

Keywords: Tactile Learning; Inclusive Education; Geometry Learning; Visual Impairment; 3D Pen

1 Introduction and Motivation

Inclusive education is an important objective of modern educational systems, aiming to ensure equal access to quality education for all students, including those with disabilities. Students with visual impairments require specific teaching approaches, adapted materials, and appropriate compensatory aids in order to fully participate in the educational process. Although Slovak legislation formally guarantees this right under Act No. 245/2008 on Education [7], practical barriers persist, particularly in non-specialized schools. Limited financial resources, insufficient teacher training, and restricted access to assistive educational aids often create a gap between inclusive policy and classroom reality.

In Slovakia, the Slovak blind and partially sighted union [3] connects many organizations supporting people with visual impairments. However, only two specialized primary schools focus on students with visual impairments [1, 2], while no dedicated non-vocational secondary school exists. Consequently, many students continue their education in mainstream secondary schools, where adequate support is not always available. These challenges are especially evident in mathematics education. While some subjects can be adapted relatively easily,

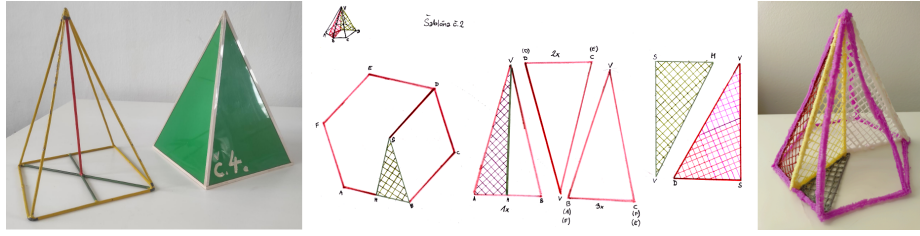


Fig. 1. The models typically available in schools in Slovakia (left). Hand-drawn template used for constructing the tactile model (center) and the corresponding completed geometric solid (right).

e. g. by transcribing textbooks into Braille, geometry requires carefully designed tactile representations. This need becomes even more pronounced in solid geometry, where learners rely heavily on physical models to construct accurate mental representations of spatial relationships.

The practical relevance of this challenge became evident through collaboration with a specialized school for students with visual impairments [1], which requested the development of tactile teaching aids to support the instruction of solid geometry at the seventh-grade level. At this stage, the curriculum covers topics such as the volume and surface area of basic solids (e.g. cubes, prisms, and pyramids) as well as spatial elements including body diagonals. The school emphasized the need for solutions that are affordable, easily producible, and adaptable to students' learning needs.

Currently available models in Slovak schools are usually designed either as solid objects or as wireframe structures without filled faces, see Fig. 1 (left). While solid models allow students to form a general mental representation of the shape, they do not enable exploration of internal geometric relationships. In contrast, wireframe models often hinder the formation of a complete mental image and may lack important elements, such as the height of the solid, body diagonals, or face diagonals. As a result, visually impaired students may experience reduced engagement and fewer opportunities for active participation.

2 Related Work

During our initial exploration, we identified primarily open-source repositories of 3D-printable models as available resources for teaching spatial geometry. However, these solutions typically require access to 3D printing technology and digital modeling skills, limiting their practical usability in everyday classroom settings.

Although several repositories providing ready-to-print 3D models for geometry teaching are available (e.g., [16]), prior research suggests that the creation, adaptation, and practical classroom use of such materials remain challenging for educators. According to [12], teachers often prefer real objects and physical three-dimensional models because they provide a more natural learning experience for students; however, such materials are frequently difficult to obtain and

can be costly. In contrast, many advanced technologies (e.g. 3D printing) remain underutilized, as they are often perceived as expensive, complex, and not always well aligned with specific instructional goals. Research [4] indicates that tactile graphics can be challenging for students with visual impairments when they are overly complex or poorly designed, underscoring the need for materials that align with principles of tactile perception and usability.

Research on the use of 3D pens in geometry instruction has primarily advanced through a five-year program led by Ng and colleagues [11]. Early work demonstrated that students developed concepts such as tangent lines and solids of revolution through the physical manipulation of mathematical representations, which improved spatial visualization [10]. Subsequent studies introduced lesson designs for teaching the properties of prisms, pyramids, and cross-sections [8] and compared learning outcomes between students using 3D pens and those working with dynamic geometry environments [9].

Collectively, this body of work highlights the role of embodied interaction in mathematics learning, suggesting that 3D pens support visualization, investigation, and retention of geometric relationships.

While existing research demonstrates the educational potential of 3D pens among sighted learners, their capacity to support tactile learning for students with visual impairments remains underexplored. This gap is especially evident in the Slovak secondary education context. Research on effective methods and teaching strategies for spatial geometry instruction for visually impaired students is still limited, despite the recognized importance of inclusive mathematics education. This highlights the need for further investigation to support accessible learning and ensure equal educational opportunities for all.

3 Methodology

An important consideration for implementing assistive technologies in educational settings is their accessibility and usability for teachers themselves, who are key facilitators of learning. In many school systems, including Slovakia, the average age of teachers exceeds 45 years [17], suggesting a predominantly experienced but potentially less technology-oriented workforce. Therefore, approaches that minimize the need for advanced digital skills are particularly valuable, as integrating complex software or design tools for creating instructional materials can present a significant barrier to adoption by education professionals.

Also, as Slovakia lacks specialized non-vocational secondary schools for certain student populations, those intending to pursue higher education are typically integrated into mainstream secondary schools. The proposed approach enables sighted students to support their integrated peers by creating customized physical models using 3D pens. Such practices facilitate the understanding of spatial concepts and promote inclusion, integration, and the reduction of barriers between typically developing and integrated students. Furthermore, this approach contributes to raising awareness and fostering sensitivity within the broader public toward the needs of visually impaired students.

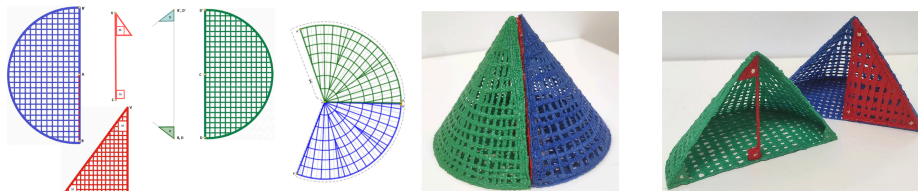


Fig. 2. Cone model enabling exploration of both its internal structure (Pythagorean triangle) and its overall shape thanks to the possibility of separating it into two parts.

To address these objectives, we selected a 3D printing pen as the primary fabrication tool. It is a handheld fabrication device that enables the creation of three-dimensional objects through the controlled extrusion of heated thermo-plastic filament, the specifics on its usage can be found in [13, 14]. Functionally similar to desktop 3D printers, the pen melts plastic material and deposits it layer by layer. A 3D pen requires minimal technical setup and can be used almost immediately after activation. Another important advantage is its cost accessibility, positioning it as a feasible option even for resource-constrained schools.

Based on the needs of the partner school [1], our main objective was to design templates for creating tactile models of geometric solids using a 3D pen that can be used in solving tasks focused on the application of the Pythagorean theorem. During the initial consultation with a special education teacher from this school, a key limitation of existing wireframe models (Fig. 1, left) was identified. Specifically, students are unable to correctly recognize right triangles, as the available models represent only the edges without filled surfaces. As a result, students cannot perceive the complete triangular shape through touch and often become disoriented among the individual edges, making it difficult for them to understand the relationships between geometric elements.

Therefore, we designed wireframe models of solids in which all relevant right triangles are made accessible by touch, including their filled interior surfaces, as shown in Fig. 1 (right) and Fig. 3 (left). The models were intended to facilitate a task in which the students were required to determine the height of the solid based on the known lengths of its edges, as well as to solve similar tasks. By physically exploring the structure, the students could locate the relevant right triangles and apply the Pythagorean relationship to calculate the unknown variable.

Although the wireframe model proved highly beneficial for students, the absence of filled surfaces (faces) did not provide students with sufficient sensory feedback for a comprehensive understanding of the shape; the individual faces had to be mentally inferred, requiring a level of spatial abstraction that can be particularly demanding for learners with congenital blindness. We filled the faces and added magnets so that the interior of the models was accessible, and the modified models were tested again, see Fig. 2.

The models with filled faces were subsequently presented to a special education teacher with over 30 years of professional experience and were tested by two

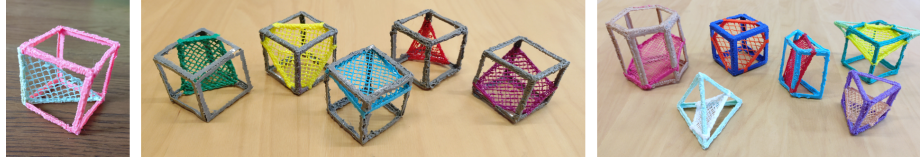


Fig. 3. Wireframe model of a cube (left) with an internal triangle illustrating the computation of the space diagonal using two applications of the Pythagorean theorem. Tactile models of planar cross-sections of solids created during workshops (center) and created by pre-service mathematics teachers (right).

students from [1]. The teacher evaluated the tested model as the most suitable among all the proposed designs, lending strong credibility to this assessment despite the small sample size of student testing.

4 Practical Validation and Educational Workshops

The ability of in-service teachers without previous experience with the 3D pen was tested during practical workshops in Bratislava (09/2025, [14]) and Prague (02/2026, [15]). After a brief instruction, they were able to create geometric models within 70 minutes, see Fig. 3 (center). Around 50 participants reported a high level of satisfaction with the clarity, practicality, and immediate applicability of the activity in classroom settings. We also received several invitations from various schools and universities in Slovakia to organize a similar workshop for students and pre-service teachers during the academic year 2025/26.

In addition to teacher workshops, the approach was also tested directly with sighted students in classroom settings [13] where students collaboratively created models as part of mathematics lessons. These activities elicited strong engagement, and students aged 12–13 were able to use the 3D pen without significant difficulty.

We also decided to incorporate this approach into the training of pre-service mathematics teachers. Several examples of the students' work can be seen in Fig. 3 (right); further details are provided in [6]. This phase was closely coordinated with the Support centre for students with special needs at the Comenius University in Bratislava [5].

5 Contribution and Discussion

In this paper, we identified the broad potential for the application of 3D pens in the education of visually impaired students. In particular, we highlight the rapid prototyping and testing of solutions directly in teaching practice and their fast, cost-effective implementation and reevaluation with a rapid feedback loop.

While open-access repositories provide 3D printable models for mathematics instruction, modifying these resources typically requires proficiency in CAD or

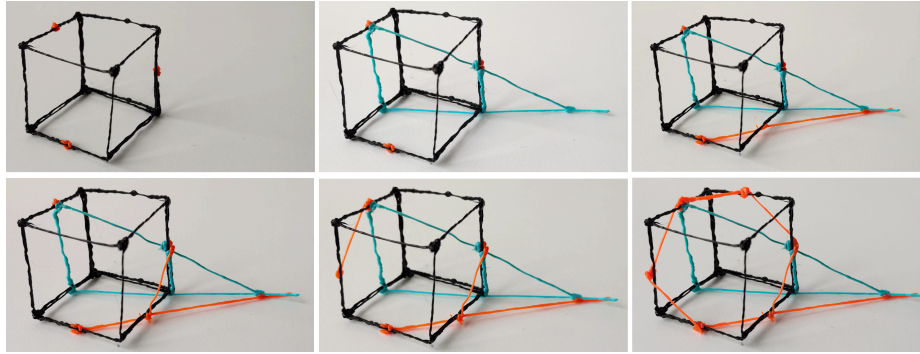


Fig. 4. Step-by-step construction of a planar cross-section of a cube.

similar software, which may exceed the technical comfort level of many in-service teachers. In contrast, 3D pens allow for direct creation and customization of tactile models without specialized software, thereby lowering technical and cognitive barriers. Templates for constructing the models may be produced either manually or with the support of graphical software, depending on the educator's skills and preferences. The manually created template in Fig. 1 (center) was produced by a 13-year-old student, highlighting the low technical barrier of the approach.

Additionally, the material and equipment costs associated with 3D pens are considerably lower than those of traditional 3D printing setups, making them a cost-effective option for producing personalized learning aids. Beyond financial considerations, 3D printing may be less suitable for models involving suspended or diagonal structures, as these often require support elements that must be manually removed. Production time presents another limitation: printing a single model may take several hours, particularly when a larger size is necessary for meaningful haptic exploration. By comparison, 3D pens support faster fabrication of appropriately scaled models while maintaining low material costs.

The 3D pens also support step-by-step constructions since some spatial geometry constructions require a series of complex steps, e. g. using auxiliary planes and/or lines. Educators or assistants can guide visually impaired students through each stage of the construction in real-time (see Fig. 4). This process-oriented approach supports deeper understanding by linking the formation of the model with the underlying geometric reasoning.

An additional advantage of our approach lies in its potential for home use. Due to the relatively low cost and ease of operation of 3D pens, parents may acquire the device and actively support their children's learning outside the classroom, supporting their individual learning needs.

Despite their advantages, 3D pens also present several limitations that should be considered in educational contexts. Models produced with 3D pens tend to be more fragile than those fabricated through conventional 3D printing, which may affect their long-term durability under frequent classroom use. However, their ease and speed of fabrication make them particularly suitable for rapid

prototyping of geometric configurations or instructional tasks. Once a model has proven to be pedagogically effective and sufficiently illustrative, teachers may consider producing a more durable version using 3D printing. In addition, the geometric precision of hand-fabricated models can vary depending on the maker's skill level, potentially leading to minor irregularities in shape or proportion.

Also, as a relatively recent technology, the quality of commercially available 3D pens is not yet fully standardized. Lower-cost devices may exhibit technical shortcomings, such as overheating power adapters, highlighting the importance of careful product selection to ensure safe and reliable operation in school environments.

6 Conclusion

This paper presents 3D pens as an accessible tool for creating tactile models to support geometry teaching for students with visual impairments. The approach addresses practical limitations of traditional fabrication methods by offering a low-cost, flexible, and teacher-friendly solution for producing personalized learning materials. Classroom use shows that these tactile models can support spatial reasoning and problem-solving, especially in tasks involving geometric relationships in three-dimensional structures. Their adaptability to individual learning needs further emphasizes their pedagogical value.

So far, our research has focused on a proof of concept, demonstrating the feasibility of using 3D pens in educational settings across different age groups and levels, including teachers, mainstream students, and integrated students. The research involved exploratory probes, case studies, and small-scale collaboration events at schools. Although feedback was largely informal, it was consistently positive, supporting further investigation. Future work will involve systematically designed, rigorous pedagogical research to obtain reliable, measurable, and actionable results.

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