# Text vs. 3D Models: Comparing Traditional and 3D-Printed Learning Materials in Primary Science Education

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**Abstract**

Building on research highlighting the importance of touch and multisensory experiences in learning, this paper explores the development and educational potential of 3D-printed tactile models for primary science education, with a focus on celestial bodies. The models were created using open-source grayscale elevation maps of celestial bodies, which were processed through a custom computational pipeline to generate spherical surfaces and then 3D-printed in nylon. These tactile, three-dimensional models were introduced in a primary school classroom and evaluated in a comparative study against traditional text-based materials. Results indicate that students who interacted with the 3D models scored significantly higher on a quiz assessing their understanding of the relative sizes of celestial bodies, compared to peers who studied the same content through text. This suggests that tactile 3D models can enhance conceptual understanding, particularly in grasping spatial dimensions. Given the increasing availability of 3D printers in educational settings, this approach might hold potential as a complementary tool to traditional teaching strategies. Moreover, it may offer a more inclusive learning resource for students who cannot rely on visual input to the same extent as their peers.

**Keywords:** multisensory learning, inclusive education, tactile education, tactile maps, tactile learning, 3D printing, 3D models for STEM education

# 1 Introduction

## 1.1 Background and Motivation

Although tactile-based approaches are increasingly recognized in the scientific literature for their cognitive and perceptual benefits, their integration into education remains limited. According to previous research [1, 2], tactile perception serves as a foundational reference in early development, supporting the visual system in acquiring accurate representations of size and shape. In disciplines such as mathematics and geometry, tactile interaction has been shown to support the comprehension of abstract and spatial concepts that include numerical magnitude, shape manipulation, and three-dimensional relationships [3, 4].

Nevertheless, there is a marked disconnect between empirical findings and current teaching practices. A recent survey by Cuturi et al. [5] highlights that although many educators recognize the value of tactile experiences for specific topics, these methods are rarely included in teacher training. This preference for standardized, easily assessable content, typically delivered through vision (e.g., text and images), limits opportunities for multisensory engagement. As a result, educational materials often overlook the potential of integrating multiple sensory modalities to more effectively convey diverse types of information [6].

These insights might be especially relevant in the learning of geography and science, where 2D representations, such as maps, dominate educational materials. While these tools are efficient, low-cost, and widely used [7], they present significant abstraction demands. Interpreting contour lines, understanding scale, or visualizing three-dimensional objects from a two-dimensional representation can be difficult for children [8, 9]. Another limitation of these methods is their poor inclusivity. Indeed, students with special needs, for example the ones with visual impairments, often face additional barriers with respect to their peers when learning from conventional materials [10, 11]. Additionally, besides the sensory channels in play, previous studies report that children benefit from active hands-on learning environments [12–14].

Recent studies show that students engaging with three-dimensional physical models, rather than relying solely on two-dimensional representations, demonstrate improved conceptual understanding, spatial reasoning, and better academic performance [15, 16]. In particular, hands-on activities involving three-dimensional models have proven especially effective in disciplines that require learners to grasp complex spatial relationships and physical properties, like biology, chemistry, and geology [15–17].

This supports the need to further investigate whether 3D models offer measurable advantages over traditional 2D textual descriptions in scientific and geographical concepts such as the relative size, spatial positioning, and surface characteristics of the object under study. To validate and expand upon these preliminary findings, 3D printing could represent a promising tool. This recent technology is spreading in schools [18, 19] and has already been shown to have positive effects on various aspects, including promoting creativity and analytical thinking, enhancing problem-solving skills, and improving spatial visualization abilities [20, 21]. Moreover, 3D printing education has been shown to increase student motivation and engagement, support interdisciplinary teaching like STEAM education, and enhance overall learning processes across various school subjects [20, 21]. It has also proved particularly valuable as an assistive technology for students with physical impairments, e.g., blind or low-vision students, by facilitating the cheap and rapid production of tactile educational materials, thus contributing to more inclusive learning [20].

In light of all these considerations, we designed and implemented 3D models of celestial bodies and compared them with traditional learning methods to investigate whether this innovative technology, still emerging within schools, could enhance students' understanding of spatial positioning, relative size, and surface characteristics of these astronomical objects.

### 1.2 Overview and hypotheses

This manuscript is structured into two main parts. The next section describes the technological process that led to the development of scaled 3D models of celestial bodies. Then, a comparative user study conducted with elementary school students is presented. It aimed at testing whether the use of 3D models facilitates the learning of scientific concepts (i.e., position, size, and surface) more effectively than reading traditional text-based materials.

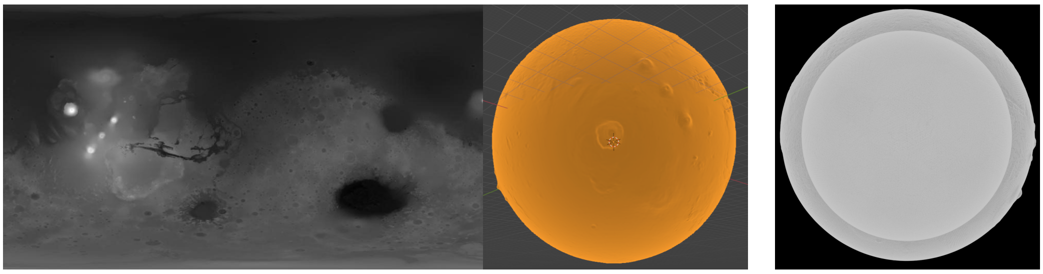
Based on the above-reported previous literature highlighting the benefits of multisensory learning and three-dimensional learning tools, we formulated the following hypotheses:

- H1 Students who interact with 3D models will score higher on quizzes assessing their understanding of planetary size, position, and surface features compared to those who read equivalent information in text format.
- H2 Students using 3D models would report greater enjoyment during the learning activity with the 3D models than students in the text condition.

## 2 Design and Fabrication of the 3D Planetary Models

### 2.1 Computational Modeling Process and Printing Workflow

To create tactile 3D-printable models, we started from open-source grayscale images where each pixel represents the elevation of the terrain. In these images, grayscale values range from 0 to 255, where 0 corresponds to the lowest level and 255 to the highest elevation (an example is shown in Figure 1a). The modeling process, enabled by a custom code, begins with generating an icosahedron, a polyhedron composed of 20 triangular faces. Each triangular face is recursively subdivided eight times to produce a highly detailed mesh that approximates a smooth sphere. Each point on the spherical surface is then converted from Cartesian coordinates (x, y, z) to geographic coordinates (latitude and longitude), enabling the mapping of real elevation data from the grayscale images onto the mesh. The code performs interpolation between pixels to assign precise elevation values. Elevations are scaled and added to the planetary radius, simulating terrain reliefs (raised areas) and depressions (lowered areas) relative to a uniform spherical surface. This process results in a realistic 3D representation of



(a) (b) (c)

**Fig. 1**: Some steps of the Mars modeling process. (a) Grayscale image of the planet's surface, provided by NASA. (b) Spherical mesh of the surface. (c) Section of the model showing the inner and outer shells.

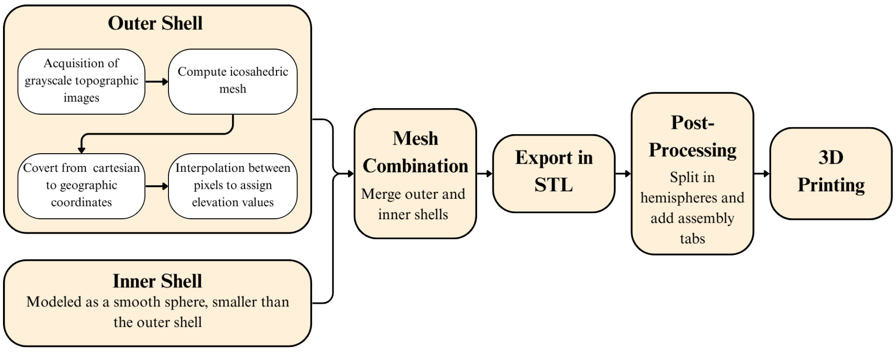



**Fig. 2**: The presented workflow for generating 3D-printable celestial bodies models.

the planet's topography (Figure 1b). In parallel, the code generates a second, slightly smaller smooth sphere without elevation data, representing the planet's interior. This inner sphere creates a "hollow shell" effect, making the final model lighter and more suitable for 3D printing. The two surfaces—outer with reliefs and inner smooth—are combined by constructing two triangular meshes, which together form a single solid 3D object (Figure 1c). The final model is exported in STL (STereoLithography) format, compatible with common 3D printing technologies. After generating the 3D models, the Python script outputs STL files that are subsequently processed with Grasshopper for Rhino [22]. This step involves splitting the final planetary models into two hemispheres and creating interlocking tabs and slots. This design enables the separate printing of the two halves, which can later be easily assembled by snapping them together. The final models were printed using Selective Laser Sintering (SLS) technology in nylon, providing durable, detailed, and tactilely suitable objects. A summary flow diagram of the process is shown in Figure 2.

(a) (b)

**Fig. 3**: Examples of tactile models of celestial bodies. (a) From left to right: Mercury, the Moon, Mars, and Earth. (b) A user exploring the 3D model of the Earth.

### 2.2 Description of the 3D-printed models

Using Earth's diameter fixed at 20 cm as a reference scale, the diameters of the other celestial bodies were calculated proportionally as follows:

- Venus (scale 0.95): 19 cm
- Mars (scale 0.53): 10.6 cm
- Mercury (scale 0.38): 7.6 cm
- Moon (scale 0.27): 5.4 cm

This scale allows for clear visualization of relative sizes among the planets and the Moon, with Earth as a reference. The choice of a 20 cm diameter for the Earth, along with the proportional dimensions of the other celestial bodies, was made to ensure that the models would be small enough to be lifted and handled by children, yet large enough to allow for the observation and tactile exploration of surface details. Figure 3 contains pictures of the models.

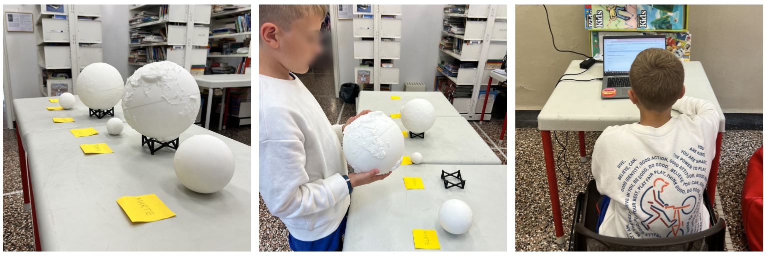
## 3 Comparative User Study

### 3.1 Participants

Twenty-one children from a fourth-grade classroom participated in the study (11 females, 10 males; age: $9.39 \pm 0.59$). All participants were Italian speakers and had not yet studied the topic of planets as part of their school curriculum. The experimental session was approved by the regional ethics committee. Prior to participation, written informed consent and data processing permissions were obtained from the children's parents or legal guardians.

### 3.2 Task

The experiment took place in the library of the elementary school attended by the participants. Each participant completed the task, which was divided into two phases, individually. The first phase, lasting five minutes, involved interaction with the educational material. Some students engaged with 3D models of celestial bodies ($N = 14$; Figures 4a-4b), while others read a text. In the 3D model condition, the celestial body



(a) (b) (c)

**Fig. 4**: Experiment setup. (a) Arrangement of 3D-models with labels. (b) A participant exploring the models using vision and touch. (c) A participant completing the quiz and the final questionnaire.

models were arranged on a table in the same order (starting from the Sun) as their real counterparts in the solar system. Each model was accompanied by a label in Italian indicating the name of the corresponding celestial body. The text-based material, written in Italian and consisting of 535 words, resembled a typical school textbook. It included images of each celestial body, a summary image of their relative positions in the solar system, and a summary table. The content was approved by the participants' teacher for both appropriateness and length. We ensured that all information regarding the size, position, and surface morphology of the celestial bodies was equally available in both conditions. In the second phase, participants completed a quiz and a brief satisfaction survey using a laptop (Figure 4c). There was no time limit for this phase. At the end of the experiment, the researchers conducted a debriefing session, explaining the study's goals and rationale to each participant. Children who had only read the text materials were also given the opportunity to explore the 3D models, ensuring they did not feel excluded or disadvantaged compared to their peers.

## 3.3 Measures

Data were collected through a questionnaire administered on a laptop using the open-source platform SoSci Survey [23].

### 3.3.1 Quiz

The quiz consisted of three sections, each corresponding to one of the target categories: size, relative position of the planets, and surface features. Each section included five multiple-choice questions. For example, a question from the surface category asked: "Which features are most evident on the surface of the Moon? Craters, Plains, High Mountains." To ensure clarity and age-appropriateness, the quiz was reviewed and approved by the participants' mathematics and science teacher prior to administration.

### 3.3.2 Survey

In addition to basic demographic information (age and gender), the survey included a brief feedback questionnaire to assess participants' enjoyment of the activity. Children were asked to rate how much they liked the experience using a 5-point Likert scale (1 = not at all, 5 = very much), displayed as stars rather than numbers to facilitate comprehension [24]. In a follow-up question, they were invited to report emotions felt during the activity, choosing among "happiness", "interest", "boredom", or entering other free-text responses. The feedback section was intentionally kept brief, as the computer-based quiz was already cognitively demanding. This design choice aimed to reduce cognitive load and maintain the children's attention.

## 3.4 Data Analysis

The data were downloaded from Sosci Survey in table format. Using a Python script and the Pandas library, the data were processed by calculating the mean score of each student for each category, followed by the overall mean, standard deviation, and standard error of the mean across all students. The processed and formatted data were then analyzed using the free statistical software Jamovi [25]. To compare the two experimental conditions, independent samples tests were conducted. The Shapiro-Wilk test was used to assess the normality of the data and determine whether parametric or non-parametric tests were appropriate. Given the directional hypotheses of the study (i.e., that one condition would result in higher scores than the other), one-tailed tests were employed.

## 3.5 Results

### 3.5.1 Performance in the knowledge assessment

The first hypothesis (H1) sustained that students who interacted with 3D models would achieve higher scores on quizzes assessing their knowledge of planetary size, position, and surface compared to those who read a text. The results, summarized in Table 1 and represented in Figure 5, were analyzed using one-tailed independent samples t-tests for each knowledge category. The analysis revealed a statistically significant difference in favor of the 3D models group for the size category ($p = 0.034$). No significant differences were found for the surface category ($p = 0.217$), although the 3D models group showed moderately higher scores than the Text group. For the position category, the scores were very similar across both conditions and no statistical difference was detected ($p = 0.462$). Therefore, H1 can be considered partially supported. Further research with a larger sample size is needed to explore the potential emergence of additional effects.

### 3.5.2 Enjoyment of the activity

Hypothesis 2 stated that students who interacted with 3D models would report a higher level of enjoyment compared to those who engaged with text. To assess this, students rated their enjoyment on a 5-point Likert scale (1 = not at all, 5 = very much). The results indicated high levels of enjoyment in both groups: the 3D models group reported a mean score of $4.79 \pm 0.579$, while the Text group reported a mean of $4.86 \pm 0.378$. A Mann-Whitney test revealed no statistically significant difference between the two groups ($p = 1.000$), thus H2 was not supported. In response to the

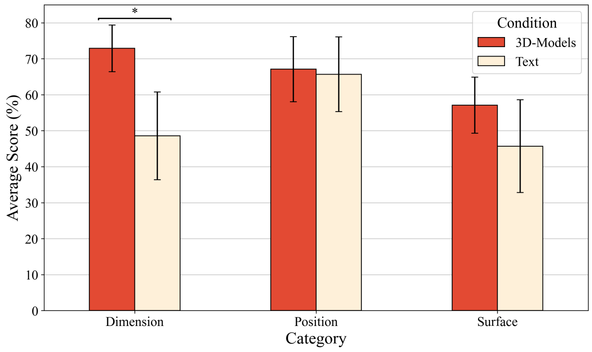



**Fig. 5**: Average percentage of correct answers in the quiz for each category (dimension, position, surface), grouped by educational tool (3D-models or text). Error bars represent the standard error of the mean.

| **Category** | **Condition** | **Mean** | **SD** | **SE** | **p** |
|---|---|---|---|---|---|
| Dimension | 3D-Models | 72.9 | 24.3 | 6.5 | 0.034* |
| | Text | 48.6 | 32.4 | 12.2 | |
| Position | 3D-Models | 67.1 | 33.8 | 9.0 | 0.462 |
| | Text | 65.7 | 27.6 | 10.4 | |
| Surface | 3D-Models | 57.1 | 29.2 | 7.8 | 0.217 |
| | Text | 45.7 | 34.1 | 12.9 | |

**Table 1**: Average quiz scores in percentage on the size, position, and surface of celestial bodies, based on the educational tool used. SD and SE indicate standard deviation and standard error of the mean, respectively. The reported p-values refer to the results of independent samples t-tests.

open-ended question "How did you feel while participating in the activity?", students' answers were categorized into three main emotional states: happy, interested, and bored. The majority of students in both groups reported feeling interested (71.4% in both conditions), while a smaller proportion reported feeling happy (28.6% in the 3D models group and 42.9% in the Text group). Only one student, from the Text group, reported feeling bored. In the free-response section, three students in the 3D models group each used a different adjective to describe their feelings during the task: "thoughtful", "attentive", and "curious", while one student from the Text group described themselves as "surprised". At present, these data do not reveal evident differences between the two learning conditions. However, this might change with a larger sample size.

# 4 Discussion

This study illustrates the process of developing 3D models for science education in primary schools, starting from open-source satellite images. The proposed approach leverages accessible and customizable technology, and, thanks to the growing availability of 3D printers, it holds potential for broader dissemination in educational settings [18, 19].

Our results partially align with previous research showing that 3D models can improve learning performance in students [15, 16]. Specifically, the higher scores in the dimension category observed in the 3D model condition support prior findings from developmental psychology suggesting that children often rely on tactile input to perceive and estimate object size [1]. This confirms the importance of multisensory learning and highlights the potential of using three-dimensional models in science learning, which could be initially inserted alongside traditional teaching methods.

No significant differences, instead, emerged regarding students' reported enjoyment of the activity between the two conditions. One possible explanation is that, according to experimenters' qualitative observations, the participants were enthusiastic about engaging in a non-routine task, likely influenced by the novelty of the experience and a possible desire to make a good impression on the experimenters. This novelty effect, combined with a desire to please the experimenters, may have led children to rate the activity positively regardless of the condition, rather than as a reflection of a rational evaluation.

Among the limitations of this study, we report the sample size. It was relatively small, as the current data set comes from an initial, recently collected pool of participants. We plan to expand the sample to explore whether additional effects might emerge with increased statistical power. Another limitation is represented by the assessment method, which may have influenced the findings. Only one quiz was administered immediately after the learning phase. Future studies could address this by including multiple training sessions (which would also help reduce the novelty effect) and by running knowledge assessments both immediately and after some days. This would allow for a better understanding of which types of information are retained over time and through which modality (text or 3D models).

Importantly, as this approach may also support educational inclusion for students with special needs, particularly those with visual impairments [20], we plan to extend this work to include this category of students in order to directly assess the inclusiveness of the technology and its potential benefits in special education contexts. Another possible future improvement would be to study the dynamics of students' exploration behavior, either by sensorising the objects [26] or by applying computer vision techniques, to gain deeper insights into how students interact with the materials.

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