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Stars Beyond Sight: Developing a Universally Accessible 3D Tactile Resource for Teaching Constellations to Visually Impaired Learners[1]

Marcos Cesar Danhoni Neves[i,ii,iii], Milena Galvani Rodrigues de Almeida[i], Awdry Feisser Miquelin[i], Josie Agatha Parrilha da Silva[ii,iii], Cristiane Aparecida de Pereira Lima[i], Carla Emilia Nascimento[i]

[i)] *Post-Graduation Program in Science and Technology Teaching (PPGECT), Paraná Federal Technological University (UTFPR - Ponta Grossa), Brazil.*

[ii)] *Post-Graduation Program in Science and Mathematics Teaching (PCM), State University of Maringá (UEM), Brazil.*

[iii)] *Post-Graduation Program in Science and Mathematics Teaching (PPGECEM), State University of Ponta Grossa (UEPG), Brazil.*

Abstract:
Astronomy education heavily relies on visual resources, presenting significant barriers for learners with visual impairments or BLV (blind and low vision). This study addresses this gap by developing and evaluating a universally accessible 3D tactile resource for teaching constellations. Grounded in Vygotsky's socio-cultural theory and principles of inclusive education, the research employs an action research methodology within a Brazilian planetarium context. Utilizing 3D printing technology, 89 tactile constellation models (covering IAU-defined regions) were designed in AutoCAD based on precise celestial coordinate conversions and star data from SIMBAD. These models integrate raised constellation figures, scaled stars, and planned auditory descriptions. The findings detail the rigorous technical process of data manipulation and model creation, alongside the selection of free audio playback software. Future qualitative feedback from planetarium professionals ("planetarists") and visitors may intuitively suggest that the resource could increase engagement and accessibility. The study highlights the potential of 3D printing to create inclusive, multisensory astronomical tools and underscores the need for further development of accessible pedagogical materials in science education. Challenges related to durability, precise star positioning, and integration into educational practice are discussed.

***Keywords**: Astronomy Education, Inclusive Education, Visual Impairment, Tactile Models, Assistive Technology.*

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[1] At its current stage, this research has not involved interactions with human participants (BLV students, planetarium professionals, or teachers) and therefore did not require review by COPEP (the Brazilian Research Ethics Committee)."

I. Introduction

Astronomy, humanity's oldest science, has always depended on observation and visualization. From ancient civilizations charting celestial movements to the advancements of modern astrophysics, our understanding of the cosmos has been intrinsically tied to sight. This reliance presents a profound challenge for learners who are *blind* or *have low vision* (BLV), often excluding them from engaging with core concepts such as stellar patterns and constellations. In Brazil, approximately 3.1% of the population aged two years or older lives with visual impairment or low vision (IBGE, 2023; Gomes, 2023), representing a significant demographic underserved by traditional astronomy education.

While inclusive education has gained momentum since Brazil's adoption of the Salamanca Statement (1994) and the enactment of specific legislation—such as Brazilian Law 13,146/2015 (Statute of the Person with Disability – BRASIL, 2015) a critical gap remains in accessible science education resources, particularly in astronomy. Existing materials often lack durability (e.g., cardboard, EVA foam) or fail to offer a truly multisensory, concrete understanding of spatial celestial relationships. Visual aids continue to dominate planetariums and classrooms, leaving BLV learners reliant on verbal descriptions that struggle to convey spatial configurations and scale.

In the work of Abreu *et al* (2019), accessibility was analyzed in fifteen Brazilian planetariums and astronomical observatories, revealing modest progress primarily in physical infrastructure, while communicational and attitudinal dimensions remain largely overlooked. The study highlights a lack of robust institutional policies and a shortage of trained personnel to support individuals with disabilities. Although some isolated initiatives exist, the overall landscape is still characterized by structural and symbolic barriers, underscoring the need for greater investment and institutional commitment to achieve full inclusion.

The research conducted by Varano & Zanella (2023) proposes and evaluates a multisensory representation of invisible astronomical data, aiming to include blind and visually impaired individuals. By replacing figurative visual representations with tactile, auditory, and arbitrary visual stimuli, the authors minimize cognitive distortions and promote a more conscious understanding of scientific phenomena. Grounded in the principles of Universal Design for Learning, the study demonstrates that such approaches not only expand access to science but also enrich the meaning-making process for all audiences. The exhibition "Sense the Universe" is presented as a tangible and promising outcome of this initiative.

3D printing technology presents a promising solution to this challenge. Its capacity to produce accurate, durable, and manipulable physical models lays the groundwork for creating tactile representations of abstract astronomical concepts. Moreover, its potential for customization aligns with the principles of Universal Design for Learning (UDL), enabling the development of resources that support diverse learners—including those with full sight.

Fernandes and Zanella (2022) presented a study exploring how visually impaired adults experience visits to two science museums in Rio de Janeiro, using an innovative qualitative approach involving subjective cameras. The findings indicate that while physical accessibility is relatively well developed, communicational and attitudinal dimensions still present significant gaps. Educators played a key role in fostering inclusion; however, informational resources and permanent strategies to ensure visitor autonomy remain insufficient. The article emphasizes the importance of active listening and organizational change, reinforcing that full inclusion requires more than infrastructure—it demands institutional commitment to diversity and the active participation of people with disabilities.

This paper, part of an ongoing doctoral research project, seeks to address the accessibility gap in astronomy education. The central research question is: What are the contributions of a universal didactic and technological resource to the teaching and learning of constellations? Specifically, the project focuses on:

1. Designing and fabricating universally accessible 3D tactile models of constellations.
2. Creating detailed auditory descriptions to accompany the tactile models.
3. Identifying and implementing free software for auditory description playback.
4. Analyzing the potentialities and limitations of the resource for teaching and learning.
5. Developing supporting materials for educators.

This paper presents the theoretical framework, methodology, development process of the 3D tactile resource (Figures 1, 2a,b), and some findings from this ongoing action research.

Figure 1. Tactile celestial sphere and lunar sphere. [source: PÈREZ-MONTERO, 2019]

Figure 2a. Tactile celestial sphere. [Source: RNZ, 2016]

Figure 2b. Tactile celestial spheres. [Source: the authors]

As an addition, it is important to reference the foundational work of Grice (e.g., tactile books, 2025), Hurd (2025), Runyon (2025), Christian et al. (3D printed imagery, 2024), and the resources provided by the IAU Office of Astronomy for Development (2025). Equally relevant are the theoretical and research contributions of Wild and Trundle (DAMJANOVIC, V.; BRANSON, 2025), which explore how BLV learners engage with STEM concepts. Unfortunately, the NASA Braille books appear to have been removed from public access; when attempting to access the webpages, users are met with the message: "The cosmic object you are looking for has disappeared beyond the event horizon." Nevertheless, valuable writings by Grice (2006, 2025) remain available, and some content can still be retrieved through the Web Archive (see Figure 3).

Figure 3. A NASA Braille books.
Source: NASA, SSERVI (In: webarchive), 2025.

These references help position our project not as an isolated initiative, but as a meaningful contribution that builds upon and engages with existing global efforts. By incorporating features such as full-sky coverage and integrated audio, our approach draws from prior work while potentially expanding its scope and impact.

II. Theoretical Framework

The development and implementation of the tactile resource are guided by two interconnected theoretical pillars: Lev Vygotsky's socio-cultural theory of learning and the historical trajectory and principles of inclusive education for individuals who are blind.

Vygotsky's work (1978, 1987) offers a vital framework for understanding learning processes, particularly among individuals with disabilities. Central concepts informing this research include mediation, the zone of proximal development (ZPD), the social origin of higher mental functions, and the notions of compensation and defectology.

In the process of *mediation*, human cognition develops through interactions with the world that are facilitated by tools—both physical (such as 3D models) and psychological (such as language and symbols). The tactile constellation models serve as essential physical mediators, offering direct sensory access to astronomical concepts that are typically conveyed through visual or verbal means. For BLV learners, these models transform abstract, visually dominated content into tangible experiences, fostering deeper engagement and understanding.

In the *zone of proximal development* (ZPD), learning occurs most effectively in the space between what a learner can accomplish independently and what they can achieve with support from a more knowledgeable other (MKO). Planetarists or educators who utilize the tactile models serve as MKOs, scaffolding learners' understanding of constellations through guided exploration and dialogue facilitated by the resource.

Regarding the *social origin of higher mental functions*, advanced cognitive processes emerge through social interaction. Collaborative exploration of the tactile models among learners, guided by educators, promotes the internalization of astronomical knowledge. This shared engagement transforms external dialogue into internal understanding, aligning with Vygotsky's view of learning as a socially mediated process.

Vygotsky (1993, 2011), in his work on compensation and defectology, radically shifted the focus from disability as "defect" to a developmental perspective. He argued that organic limitations can stimulate the emergence of alternative psychological pathways and cultural compensation mechanisms. In this context, tactile models and auditory descriptions function as cultural tools that enable BLV learners to access and comprehend constellations through touch and hearing—effectively compensating for the absence of sight. Vygotsky emphasized that the goal of education is not merely integration, but the full development of personality and potential through these alternative routes. As he noted, "In the case of a blind person, the defect creates difficulties for the direct function (vision) but simultaneously stimulates the development of indirect functions (touch, hearing), which become the basis for complex compensation" (Vygotsky, 2011, p. 864, paraphrased from Portuguese source concepts).

This framework justifies the creation of *universal* resources. Vygotsky's emphasis on social mediation and cultural tools underscores the need for resources that can be used in shared social Spaces (such as classrooms and planetariums) by all learners. Such resources promote inclusion and collaborative learning rather than segregation, aligning with the principles of Universal Design for Learning.

2.1 History and Education of the Blind in Brazil

Understanding the context requires acknowledging Brazil's complex historical trajectory in the education of blind and low vision (BLV) individuals (Mazzotta, 1999; Zeni, 2005; Jannuzzi, 2006; Camargo, 2011). The Imperial Institute for Blind Boys, founded in 1854 and later renamed the *Benjamin Constant Institute* (IBC), was a pioneering institution in specialized education. However, its services initially catered primarily to the elite, excluding enslaved children and those unable to afford tuition. Early educational efforts emphasized Braille literacy, music, and crafts, often shaped by societal perceptions that associated BLV individuals with charity or limited intellectual potential (Neves *et al*, 2000).

The 1961 National Education Guidelines and Bases Law (LDB) formally incorporated special education into Brazil's educational framework, yet it upheld a predominantly segregated model through specialized institutions and private initiatives. The 1988 Federal Constitution marked a significant turning point by establishing explicit rights for people with disabilities. The adoption of the Salamanca Statement in 1994 further advanced the inclusive education movement, advocating for all children to learn together in regular schools with appropriate support. This trajectory culminated in the 2015 Statute of the Person with Disability, which enshrined inclusive education as a fundamental right.

This project is directly aligned with inclusive education policies at the federal, state, and municipal levels. In the state of Paraná, Decree No. 7,373/2018 establishes guidelines for the provision of accessibility resources. At the municipal level, Maringá's Municipal Law No. 9,785/2013 and the Municipal Education Plan (Law No. 10,126/2015) reinforce the right to education and the imperative to ensure accessibility. The development of this resource for the UEM Planetarium represents a concrete application of these mandates within the realm of non-formal education (Neves *et al,* 2023).

Despite these legal advances, significant challenges persist. A critical shortage of genuinely accessible pedagogical materials across disciplines - particularly in science and astronomy - continues to hinder effective inclusion. This research seeks to directly address this gap by developing a tangible, multisensory resource that aligns with the legal and pedagogical mandate for equitable educational opportunities.

III. Material and Methods

This study adopts a qualitative action research approach (Kemmis & McTaggart, 1988), selected for its cyclical structure of planning, acting, observing, and reflecting. This methodology enables iterative refinement of the educational resource based on its real- world application and user feedback. The research is situated within the Planetarium "Prof. Carlos Alfredo Argüello" at the State University of Maringá (UEM), Brazil, providing a dynamic setting for non-formal science education and inclusive pedagogical experimentation.

The participants in this study include planetarists and visitors. Planetarists - typically educators or astronomy graduates - are responsible for conducting planetarium sessions, guiding visitors, and mediating learning experiences. They offer valuable insights into the resource's applicability, integration into existing practices, and effectiveness in promoting inclusion. Visitors represent a diverse public engaging with the planetarium, including individuals with and without visual impairments. Their feedback is essential for evaluating the resource's usability, engagement, accessibility, and overall effectiveness from the learner's perspective.

During the centennial cycle of sessions held at the Planetarium, involving students from various academic levels, particular attention has been given to transforming imagetic experiences into tangible ones. These sessions aim to make the visual scenes projected onto the dome more accessible and engaging, especially for blind and low vision (BLV) learners. To this end, tactile experiences have been incorporated at the conclusion of each planetarium session.

One notable example is the science fiction exhibition featuring iconic imagery from the "Star Wars" franchise—a visual montage that traces the evolution of sci-fi in cinema and its role in sparking interest in themes such as astronomy, cosmology, and geology. As shown in Figure 4, a BLV student interacts with tactile elements including masks of a stormtrooper and Darth Vader, a lightsaber—experiencing its warmth and sound—and a small refractor telescope. These tactile components help reinforce and deepen understanding of the concepts explored during the immersive dome presentation, bridging the gap between imagetic and multisensory learning.

Figure 4. : Blind and low vision (BLV) student engaging in tactile experiences inside the Planetarium "Prof. Carlos Alfredo Argüello." The interactive session includes hands-on exploration of sci-fi masks, a lightsaber replica, a mechanical planetarium, an astronaut helmet, and a refractor telescope. These multisensory elements foster inclusive learning, stimulate curiosity, and support spatial and conceptual understanding of astronomy through touch and guided mediation.

Source: the authors.

Building on these experiences with school audiences, the present study will incorporate participant observation. The researcher will observe interactions between participants—both planetarists and visitors—and the tactile models during planetarium sessions. Particular attention will be given to participants' reactions, levels of comprehension, engagement strategies, and any difficulties encountered throughout the experience.

Semi-structured interviews will be conducted with both planetarists and visitors. Interviews with planetarists will focus on the practical application of the tactile resource, its perceived usefulness, challenges encountered in promoting BLV inclusion, and suggestions for improvement. Interviews with visitors will explore their interest in the resource, perceived utility, level of comprehension, overall satisfaction, and any accessibility barriers or facilitators related to the tactile models and accompanying audio descriptions.

The next phase of this research will involve a planned sample of approximately 5 to 10 planetarists and 15 to 20 visitors, including individuals with and without visual impairments. Data collection is expected to take place over a six-month period following the qualification exam. This phase will focus on gathering qualitative insights through participant observation and semi-structured interviews, assessing the usability, accessibility, and pedagogical impact of the tactile resource. The analysis of this data is anticipated to be completed and published, contributing to the broader discourse on inclusive science education.

The collected data - including observation notes and interview transcripts - will be analyzed using Qualitative Content Analysis (Bardin, 1977). This method involves systematic coding to identify recurring themes, patterns, and categories aligned with the research questions. Key analytical dimensions will include ease of use, levels of engagement, comprehension gains, challenges in integrating the resource, effectiveness of tactile and auditory components, and suggestions for improvement.

The development of the tactile resource *Constellations Within Reach* centers on a core technological product: a set of 89 universally accessible 3D tactile constellation models. This includes all 88 officially recognized constellations by the International Astronomical Union (IAU), with Serpens represented in its two distinct parts - Serpens Caput (head) and Serpens Cauda (tail).

The design process was guided by the principles of Universal Design, ensuring that the models are

usable by both sighted and blind or low vision (BLV) learners simultaneously. Each model simulates the Earth-based observer's perspective of the constellation's region in the celestial sphere, enabling multisensory engagement and inclusive learning in both formal and non-formal educational settings.
The technical development of the tactile resource is grounded in precise astronomical data.

- Data Source: Constellation boundary coordinates were obtained from the IAU- sanctioned catalog VI/49, accessible via the VizieR database (Centre de Données astronomiques de Strasbourg – CDS). This catalog defines the official celestial regions of each constellation using Right Ascension (RA, in hours) and Declination (Dec, in degrees), ensuring scientific accuracy in the spatial representation of the models.
- To prepare the constellation data for 3D modeling, Right Ascension (RA) values were converted from hours to degrees within a 0 - 360° range. Assuming a celestial sphere with a fixed radius of 100 mm, spherical coordinates (RA, Dec) were transformed into Cartesian coordinates (X, Y, Z) using trigonometric formulas. This conversion enabled accurate spatial representation of each constellation point for AutoCAD-based modeling, preserving the Earth-based observer's perspective of the celestial sphere.
  - Z = R * sin(Dec)
  - Correction Factor = $\sqrt{(\cos^2(Dec))}$ // Adjusts radius for XY plane at height Z
  - X = R * Correction Factor * cos(RA)
  - Y = R * Correction Factor * sin(RA) - A spreadsheet managed the conversion of all 13,238 boundary points.
- AutoCAD modeling:
  - Boundaries: Converted XYZ coordinates were imported into AutoCAD using the 3D POLYLINE command to trace constellation boundaries. These 2D polylines were then elevated (EXTRUDE command with "Ruled" option) using the origin (0,0,0) as a reference point to create preliminary solid boundary shapes.
  - Solid Constellation Region: A spherical shell (R=100mm, thickness=10mm) was created. The intersection (INTERSECT command) between this shell and the elevated boundary solid yielded the base "mold" for the constellation region. This mold was thickened (THICKEN command, -1mm) and unified (UNION).
  - Final Piece: A smaller sphere (R=99.5mm) was created and shelled (thickness=9mm). The constellation mold was then subtracted (SUBTRACT) from this shell, resulting in the final tactile piece representing the celestial region of the constellation.
- Star Integration: primary stars—such as Alpha, Beta, Gamma, and Delta—forming the recognizable figures of each constellation were identified using official IAU star maps. Their precise celestial coordinates were sourced from the SIMBAD astronomical database. In the tactile models, these stars were strategically positioned to protrude from the concave (inner) surface. This design choice is essential, as it allows users' fingertips to naturally settle into the model, offering a stable reference point. The raised star markers and connecting lines stand out clearly against the smooth background of the constellation region, enabling effective tactile discrimination and enhancing spatial comprehension for blind and low vision (BLV) learners.
  - Coordinate conversion was performed, using a slightly smaller effective radius (max ~91mm) to ensure stars protrude tactilely on the *inner* surface of the model.
  - Stars were modeled as spheres of varying radii (Alpha: 2.3mm, Beta: 2.0mm, Gamma: 1.8mm, Delta+: 1.5mm) and precisely positioned within their constellation region using their converted XYZ coordinates in AutoCAD. Manual adjustments were sometimes necessary for optimal tactile positioning. Stars were modeled to provide a tactile representation of their apparent brightness hierarchy (magnitude) within the constellation, a key feature for interpretation.

  - Constellation figures: lines connecting stars (based on IAU figures) were created using 3D polylines and converted into 1mm radius cylinders (SWEEP command) using a small circle as the profile.
- 3D Printing Process: The constellation models were exported as STL files and fabricated using a Creality Ender 3 32-bit FDM (Fused Deposition Modeling) printer. Polylactic Acid (PLA) filament was selected due to its durability, non-toxicity, cost- effectiveness, and superior surface finish—offering a significant improvement over traditional materials such as cardboard or foam. This choice ensures that the tactile features are well-defined and resilient, supporting repeated handling by diverse users in educational settings.

The auditory element of the resource consists of scripted descriptions for each constellation. These recordings provide contextual information, stellar characteristics, and mythological or cultural narratives, enriching the multisensory experience. Research identified suitable free software for playback (specific software named in the preliminary results), enabling user-triggered access to the audio content. This feature ensures that both blind and sighted learners can engage with the material independently, enhancing comprehension and inclusion through layered sensory input.
Finally, the iterative refinement cycle will follow the initial 3D printing phase, during which all models will

undergo a tactile quality assessment. This stage is essential for identifying and implementing necessary adaptations to the pilot project prior to formal data collection. Anticipated adjustments include:

- Revisions to the digital models (e.g., refining the thickness of connecting lines, adjusting star protrusion depth).
- Smoothing of printed components using post-processing techniques (e.g., light sanding) to eliminate any rough edges or printing artifacts that could impede tactile exploration or safety.
- Other adjustments based on initial handling by the research team and preliminary feedback from a small pilot group, which may include modifications to the size or ergonomics of the pieces.
- These adaptations will be meticulously documented. Furthermore, the need for and nature of these adjustments will themselves be considered as valuable data within the broader analysis of the resource's limitations and usability barriers during the planetarium evaluations.

The resource will be primarily implemented and evaluated within the non-formal educational setting of the Planetarium *Prof. Carlos Alfredo Argüello*, located at the State University of Maringá (see Figure 5). This environment offers a visually immersive experience for sighted visitors, while the tactile models provide a parallel, concrete sensory channel for blind and low vision (BLV) participants, thereby enhancing the overall accessibility of the space. Planetarists will be encouraged to incorporate the models into their mediation practices during sessions, fostering inclusive engagement and multisensory learning.

Figure 5. Planetarium *Prof. Carlos Alfredo Argüello* (State University of Maringá) [Source: authors]

IV. Results

As this article is derived from a doctoral qualification thesis currently in progress, the results presented primarily emphasize the development process, initial implementation, and preliminary feedback. A comprehensive analysis of the resource's pedagogical impact is still underway and will be addressed in subsequent phases of the research.

The development process resulted in the successful creation of tactile constellation models. A robust technical workflow was established to convert IAU celestial coordinates into 3D-printable formats. All 89 constellation models were designed using AutoCAD and fabricated in PLA filamento. The complex trigonometric transformations and management of extensive coordinate datasets were efficiently handled through a combination of spreadsheet calculations and AutoCAD scripting. In some cases, manual adjustments were necessary to ensure the precise positioning of stars within the mold, enhancing tactile prominence and maintaining spatial accuracy in relation to the constellation figures (see Figure 6).

On auditory description software, the research identified a cost-effective and accessible solution for managing auditory content. Audacity was selected for recording and editing the constellation descriptions due to its open-source nature and robust audio capabilities. For playback, simple and free media players—such as VLC Media Player—and accessible mobile applications were found to be viable options for both users and planetarists. These tools support user-controlled audio engagement, enhancing autonomy and inclusivity. The scripting of auditory descriptions has been completed for the initial set of constellations, laying the groundwork for multisensory integration in upcoming sessions.

PLA models demonstrated significantly greater durability and tactile clarity compared to traditional materials such as cardboard or EVA foam, thereby validating the use of 3D printing as the preferred fabrication method.

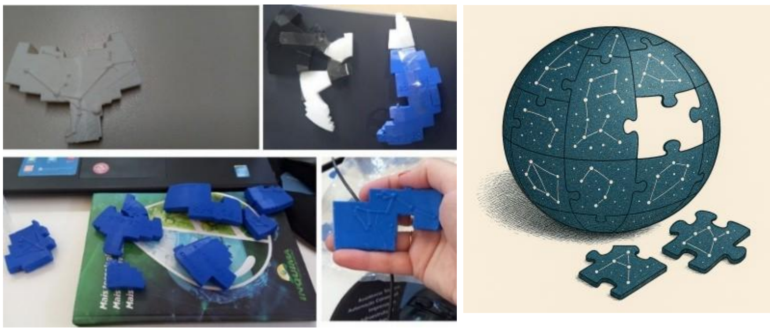

Figure 6: Photograph and schematic illustration of a 3D-printed tactile model representing the Orion constellation. Raised lines connect protruding dots of varying sizes, symbolizing the constellation's structure and indicating stars of different magnitudes.
[Source: authors]

Initial observations and interviews are expected to yield promising insights, building upon the foundational findings of Neves *et al* (2000), Costa and Neves (2002), and Costa, Neves, and Barone (2006). These findings establish a concept of "double blindness": one individual and one institutional. The individual dimension refers to blind and low vision (BLV) students themselves, while the educational dimension reflects the system's inability—or unwillingness—to promote a broad range of strategies for educating both BLV and sighted students. This limitation hinders the construction of scientific knowledge capable of transcending the constraints of common-sense understanding.

From the planetarists' perspective, the use of tactile models is expected to offer a concrete focal point for explaining the shapes of constellations and the relative positions of stars. These models benefit both sighted and blind or low vision (BLV) visitors by providing an alternative sensory pathway for understanding celestial arrangements. This approach is particularly valuable for translating the planetarium's predominantly visual presentations into accessible tactile experiences, fostering inclusive engagement across diverse audiences.

The resource is expected to serve as an active promoter of inclusion by granting non- visual visitors direct access to the core content of planetarium sessions. Experience with planetarists indicates that these professionals feel more confident and empowered when they can engage audiences through meaningful and interactive approaches. However, some planetary experts may raise practical considerations regarding the optimal timing and methods for introducing tactile models during sessions, particularly when accommodating larger groups. These discussions reflect a growing interest in expanding inclusive strategies within the planetarium environment.

High levels of engagement are anticipated from both sighted and blind or low vision (BLV) visitors, particularly in the handling and exploration of the tactile models. This expectation is supported by observations during previous planetarium sessions, where BLV students showed strong interest in interacting with science fiction-themed resources—such as touching Stormtrooper and Darth Vader masks, experiencing the heat and sound of a lightsaber, and exploring the design of a refractor telescope (see Figure XXX). The tactile nature of the constellation models is expected to be especially compelling for BLV visitors, allowing them to feel the stars and connecting lines and thereby imagine the visual sky that others are observing. This multisensory approach fosters inclusive participation and enriches the educational experience for all.

Auditory descriptions play a vital role in enhancing comprehension of constellation shapes, stellar brightness hierarchies (represented through dot sizes), and spatial relationships between stars. For example, identifying Orion as "the hunter" becomes more intuitive when users recognize the alignment of Orion's belt and sword through tactile exploration, supported by descriptive narration. Blind and low vision (BLV) visitors are expected to value this dedicated resource, which enables independent engagement with the models. Auditory descriptions will be emphasized as a crucial complementary component—delivered, for instance, via an optical QR code reader assigned to each tactile constellation. This system provides constellation-specific audio content, enriching the multisensory experience and fostering inclusive learning.

The successful development of tactile constellation models confirms the feasibility of leveraging precise astronomical data and 3D printing to produce accurate, durable representations of celestial figures. Although technically complex, the process yields a replicable methodology for inclusive educational resources. Initial feedback is expected to affirm the theoretical framework, with the models functioning as mediating artifacts in the Vygotskian sense, bridging abstract astronomical concepts and concrete tactile experiences, particularly vital for blind and low vision (BLV) learners. These models foster social interaction around a shared object, enabling planetarists - acting as More Knowledgeable Others (MKOs) - to facilitate learning within each visitor's Zone of Proximal Development (ZPD). The resource also embodies cultural compensation, offering an alternative sensory pathway (touch and hearing) to access astronomical knowledge traditionally conveyed through visual means.

A positive reception is anticipated in terms of both user engagement and perceived comprehension, aligning with the principles of Universal Design for Learning (UDL) and inclusive education. The resource is expected to empower blind and low vision (BLV) students within the planetarium context, facilitating a shift from passive listening to active, hands-on exploration. By offering multisensory access to astronomical content, the models promote autonomy, curiosity, and deeper conceptual understanding among BLV learners.

About the challenges and limitations, we pointed out:

- Scalability & cost: printing 89 high-quality models requires significant time and material costs, potentially limiting widespread dissemination without institutional support.
- Fine motor skills: highly detailed models might pose challenges for users with limited fine motor skills or tactile discrimination. Star size differentiation needs careful evaluation.
- Star position accuracy: while mathematically precise, the manual adjustments sometimes needed for optimal tactile star positioning introduce a potential source of error relative to true celestial positions at the scale of the model.
- Audio Synchronization: seamlessly integrating auditory descriptions with tactile exploration during dynamic planetarium sessions will require careful scripting and intuitive playback control.
- Generalization: research recordings will be tied to the context of the *Prof. Carlos Alfredo Argüello Planetarium*. Broader applicability in various formal and informal settings will require further study.
- Challenges in translating mythological figures into tactile models: one significant challenge lies in converting two-dimensional mythological representations of constellations into three-dimensional tactile forms (see Figure 7). This process may lead to potential misinterpretations, such as assuming that variations in model depth or height correspond to actual stellar distances—when in fact, they do not. Additionally, constellation boundaries are abstract, culturally constructed divisions of the sky that lack physical or tactile markers, making them difficult to represent in a tangible format. These limitations will be explicitly addressed during guided exploration, with mediators (planetarists and educators) encouraged to clarify these conceptual nuances to ensure accurate understanding and meaningful engagement.

Figure 7. Brazilian Indigenous constellation of the *Anta*, shown in two formats—2D representation (left) and 3D tactile model (right). The 3D version translates the cultural figure into a tactile form, enabling spatial exploration and multisensory engagement.
Source: Fiocruz, 2025

- Material selection / PLA considerations: while PLA was selected for its favorable properties—including ease of printing, tactile clarity, and cost-effectiveness—its hygroscopic nature presents a known limitation. This characteristic is particularly relevant for multi-part models or deployments in high-humidity environments, such as certain regions of Brazil. Moisture absorption over time may affect the long-term durability and precise fitting of components. As such, this factor should be considered in future iterations. Alternative materials like PETG or ASA, which offer improved moisture resistance and mechanical stability, may be explored. Additionally, post- printing sealing techniques could be investigated to mitigate hygroscopic effects and enhance model longevity.The development process and anticipated need for refinements echo findings from tactile cartography research.

The study by Gomes et al. (2024) on tactile maps underscores the critical importance of generalization and simplification for effective tactile interpretation by blind and low vision (BLV) users. Their findings reveal that excessive visual detail can hinder comprehension, reinforcing the need for clarity and intentional design in tactile resources. This insight directly informs our planned iterative refinements—such as smoothing surfaces and adjusting line thickness—and validates our design approach, which prioritizes distinct tactile features (e.g., raised star points and clearly defined boundaries) over strict adherence to visual minutiae. Moreover, their research on the cognitive strategies BLV individuals use to construct mental models from tactile inputs will be instrumental in guiding our analysis of how visitors engage with and interpret the constellation models.

V. Conclusion

This study details the development and initial implementation of a novel, universally accessible 3D tactile resource designed to support constellation education. Grounded in Vygotskian sociocultural theory and aimed at addressing a critical gap in inclusive astronomy pedagogy, the resource integrates precisely engineered 3D-printed models with complementary auditory descriptions. A rigorous technical workflow has been established and successfully executed to convert official IAU celestial data into tangible, multisensory learning tools. This approach not only enhances accessibility for blind and low vision (BLV) learners but also promotes broader engagement through multimodal interaction.

The findings are highly encouraging. The resource demonstrates significant potential to enhance accessibility by providing blind and low vision (BLV) learners with direct, multisensory access to fundamental astronomy concepts. Improved engagement is anticipated, fostering active exploration and a deeper interest in astronomy for all learners through tactile interaction. To maximize its educational impact, the resource requires mediated support—offering educators and planetarists a concrete tool to scaffold understanding of spatial relationships within constellations. Promoting inclusion in astronomy education is therefore urgent, particularly in immersive environments such as planetariums, where meaningful participation by BLV individuals can be facilitated through this innovative approach (see Figures 4 and 5).

Despite ongoing challenges related to production cost, fine-detail optimization, seamless audio integration, and broader empirical validation, the *Constellations Within Reach* resource marks a significant advancement in equitable astronomy education. It exemplifies how emerging technologies—when guided by sound pedagogical theory and inclusive design principles—can foster transformative learning experiences. By bridging sensory modalities and educational frameworks, this initiative opens new pathways for meaningful engagement with astronomical content, particularly for blind and low vision (BLV) learners.

Future work focuses on:

1. Completing the action research cycles: deeper analysis of collected qualitative data (observations, interviews) to fully understand pedagogical impact, usability barriers, and best practices for implementation.
2. Refining the models: exploring optimizations for cost and durability, evaluating star size differentiation effectiveness, and minimizing manual positioning needs.
3. Formalizing auditory integration: developing a user-friendly system for triggering and navigating descriptions during exploration.
4. Creating educator support materials: developing guides for planetarists and teachers on effectively using the resource in different contexts.
5. Exploring broader applications: testing the resource in formal classroom settings and with different age groups.
6. Dissemination: making design files and methodologies openly available to promote wider adoption and adaptation.
7. Key future step / open access and licensing: a critical next step involves making the design files (STL), auditory scripts, and methodological documentation openly available to encourage broader adoption and adaptation of the resource. We explicitly intend to release these materials under a Creative Commons Attribution-NonCommercial (CC BY-NC) license. This licensing framework permits free sharing and modification for non-commercial purposes, provided appropriate credit is given to the original creators. Open access will be implemented following the completion of the initial research and refinement phases, reinforcing our commitment to inclusive education and collaborative innovation.

As highlighted by Neves & Silva (2023), fostering inclusion in science education can be significantly advanced by exploring the intersections between art and science, particularly within informal learning environments such as museums, planetarium and science centers (figure 8). This convergence has the potential to enhance public engagement, spark curiosity, and cultivate a more nuanced and critical understanding of scientific phenomena. Through the analysis of exhibitions that integrate artistic elements into scientific narratives, the study demonstrates that aesthetics and emotion serve as powerful tools for meaning-making. Crucially, it calls for the dismantling of dichotomous perspectives that separate art and science, advocating instead for transdisciplinary approaches that honor the complexity of knowledge and the diverse backgrounds

of participating audiences.
By making celestial phenomena truly accessible, this research contributes to a more inclusive and engaging science learning environmen empowering diverse learners to explore, understand, and connect with astronomy through multisensory experiences.

Figure 8. Future Science Park "Tereza-Batista" (Planetarium "Prof. Carlos A. Argüello, Sky Square and Observatory "Cortini-Vicentini").
[Source: authors]

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References

[1]. ABREU, W. V.; ROCHA, J. N.; MASSARANI, L.; INACIO, L. G. B.; MOLENZANI, A.
[2]. Accessibilidade em planetários e observatórios astronômicos: uma análise de 15 instituições brasileiras. **Journal of Science Communication – América Latina**, v. 02, n. 02, p. 1-18, 2019, In: https://jcomal.sissa.it/article/pubid/JCOMAL_0202_2019_A04/. Access: 09/22/2025.
[3]. ALMEIDA, M. G. R. *et al.* Ensino de Astronomia na perspectiva da Educação Inclusiva a partir do levantamento sobre a produção bibliográfica no SNEA. **Ciência & Educação**, v. 30, e24043, 2024.
[4]. BARDIN, L. **L'analyse de contenu.** Paris: Presses Universitaires de France, 1977.
[5]. BRASIL. **Lei Nº 13.146, de 6 de julho de 2015 (Estatuto da Pessoa com Deficiência).** Brasília: MEC, 2015. In: http://www.planalto.gov.br/ccivil_03/_ato2015- 2018/2015/lei/l13146.htm. Access: 03/02/2025.
[6]. CAMARGO E. P. **Ensino de óptica para alunos cegos: possibilidades.** Curitiba: CRV, 2011.
[7]. COSTA, L. G.; NEVES, M. C. D. A investigação em "educação em ciência" no contexto da "educação especial': algumas considerações sobre as dificuldades da pesquisa bibliográfica. **Revista Benjamin Constant**, n. 23, s/p, 2002.
[8]. COSTA, L. G.; NEVES, M. C. D.; BARONE, D. A. C. O Ensino de física para deficientes visuais a partir de uma perspectiva fenomenológica. **Ciência & Educação**, v. 12, n. 2, p. 143- 153, 2006.
[9]. CHRISTIAN, C. A.; NOTA, A.; GRICE, N.; MADURA, T.; HURD, D. 3D printing for
[10]. teaching and exploration in astronomy for individuals with blindness/visual impairment: textured representations of imagery. **International Journal of Science Education**, Part B, n. 2, p. 304-324, 2024.
[11]. DAMJANOVIC, V.; BRANSON, S. Empowering Diverse Learners: Integrating Tangible Technologies and Low-Tech Tools to Foster STEM Engagement and Creativity in Early Childhood Education. **Educ. Sci.**, *15*(8), 1024, 2025. In: https://www.mdpi.com/2227- 7102/15/8/1024 . Access: 09/26/2025.
[12]. FERNANDES, M. P.; ROCHA, J. N. The experience of adults with visual disabilities in two Brazilian science museums: An exploratory and qualitative study. **Frontiers in Education,** v. 7, 2023 (this article is part of the Research Topic: *Inclusion in Non-formal Education Places for Children and Adults with Disabilities.* In: https://www.frontiersin.org/journals/education/articles/10.3389/feduc.2022.1040944/full. Access: 09/22/2025.
[13]. FIOCRUZ. Constelações e asterismos táteis. In: https://photos.app.goo.gl/UWfJNWKT2UtoFkZZ8 . Access: 09/26/2025.
[14]. GOMES, I. **Pessoas com deficiência têm menor accesso à educação, ao trabalho e à renda.** Brasília, IBGE. 2023. In: https://agenciadenoticias.ibge.gov.br/agencia-noticias/2012-agencia- de-noticias/noticias/37317-pessoas-com-deficiencia-tem-menor-accesso-a-educacao-ao- trabalho-e-a-renda. Access: 03/02/2025.
[15]. GOMES, Y. P. V.; ALBUQUERQUE, F. N. B.; TELES, G. A. Tactile Maps and the Geographical Reasoning of Blind Youth and Adults in Sobral, Ceará, Brazil. **Journal of Education and Learning,** [S. l.], v. 13, n. 4, 2024. In: https://ccsenet.org/journal/index.php/jel/article/view/0/51172. Access: 09/07/2025.
[16]. GRICE, N. **Touch the stars: Astronomy for people who are visualzzy impaired.** In: https://www.wvxu.org/podcast/looking-up/2025-04-18/touch-the-stars-astronomy-for-people- who-are-visually-impaired-with-noreen-grice. Access: 09/07/2025.
[17]. GRICE, N. Resources for Making Astronomy More Accessible for Blind and Visually Impaired Students. Astronomy Education Review, Volume 5, Apr 2006 - Nov 2007, issue 1. In: https://istardb.org/wp-content/uploads/tainacan-items/1018/19623/Grice-2006-Resources-for- Making-Astronomy-More-Accessible-for.pdf . Access: 09/07/2025.
[18]. HURD, D. **Out of this worls sensantions: making the universe feel like it looks.** In: https://www.unoosa.org/documents/pdf/Space4PersonswithDisabilites/Space_Pathways_for_All

_Abilities/Space_DavidHurd.pdf. Access: 09/07/2025.

[19]. IAU. International Astronomy Union. **A touch of the Universe**. In: https://iau- oao.nao.ac.jp/iau-inclusion/files/astronomy-for-blind/ and https://astrokit.uv.es/. Access: 09/07/2025.

[20]. IBGE. **Pnad Contínua - Pessoas com Deficiência 2022.** Brasília: IBGE, 2023. In: https://agenciadenoticias.ibge.gov.br/media/com_mediaibge/arquivos/0a9afaed04d79830f73a16 136dba23b9.pdf. Access: 03/02/2025.

[21]. JANNUZZI, G. M. **A educação do deficiente no Brasil: dos primórdios ao início do século XXI** (2nd ed.). São Paulo: Autores Associados, 2006.

[22]. KEMMIS, S., & McTAGGART, R. **The action research planner** (3rd ed.). Deakin University Press, 1998.

[23]. MAZZOTTA, M. J. S. **Educação especial no Brasil: história e políticas públicas**. São Paulo Cortez, 1999.

[24]. NASA, SSERVI Books. Earth from space. In: https://web.archive.org/web/20220705055031/https://sservi.nasa.gov/books/earth-from- space.html . Access: 09/07/2025.

[25]. NASA, Books. Mars Exploration Program. In: https://web.archive.org/web/20220705074331/https://sservi.nasa.gov/books/mars- exploration.html. Access: 09/07/2025.

[26]. NASA. **Hands-On Book of Hubble Images Allows the Visually Impaired to "Touch the Universe".** Press release, 10/21/2002. In: https://web.archive.org/web/20051120162312/http://hubblesite.org/newscenter/newsdesk/archive/releases/2002/28/text/ . Access: 09/27/2025.

[27]. NEVES, M. C. D.; SILVA, J. A. P. Ciência informal e o crossroad entre arte e ciência / Informal Science and the crossroad between Art and Science, **Revista Em Extensão**, 22(2), p. 68-81, 2023. In: https://seer.ufu.br/index.php/revextensao/article/view/68116/37365 Access: 09/27/2025.

[28]. NEVES, M. C. D.; COSTA, L. G.; CASICAVA, J.; CAMPOS, A. Ensino de física para portadores de deficiência visual: uma reflexão. **Revista Benjamin Constant**, n. 16, s/p, 2000.

[29]. PÉREZ-MONTERO, E. Towards a more inclusive outreach. **Nature Astronomy**, 3, p.114–115, 2019.

[30]. RNZ. **Touching the universe: astronomy for the blind**. 2016. In: https://www.rnz.co.nz/national/programmes/thiswayup/audio/201819097/touching-the-universe- astronomy-for-the-blind. Access: 03/02/2025.

[31]. RUNYON, M. **The Role and Value of the Teacher of the Visually Impaired**. In: https://www.perkins.org/resource/role-and-value-teacher-visually-impaired. Access: 09/07/2025.

[32]. SILVA, S. R.; LANGHI, R.; VILAÇA, J., P. O ensino de Astronomia para alunos cegos e a inclusão nos espaços não formais. Anais: XXIII Simpósio Nacional de Ensino de Física - SNEF, p. 1-4, 2019. In: https://www.researchgate.net/publication/335401807_O_ENSINO_DE_ASTRONOMIA_PARA_ALUNOS_CEGOS_E_A_INCLUSAO_NOS_ESPACOS_NAO_FORMAIS. Access: 09/07/2025.

[33]. UNESCO. **The Salamanca Statement and Framework for Action on Special Needs Education.** New York, UNESCO, 1994.

[34]. VARANO, S.; ZANELLA, A. Design and evaluation of a multi-sensory representation of scientific data. **Frontiers in Education**, 8, 2023. In: https://www.frontiersin.org/journals/education/articles/10.3389/feduc.2023.1082249/full. Access: 09/25/2022.

[35]. VYGOTSKY, L. S. **Mind in society: The development of higher psychological processes.** Harvard: Harvard University Press, 1978.

[36]. VYGOTSKY, L. S. **The collected works of L. S. Vygotsky, Vol. 1: Problems of general psychology.** NY: Plenum Press, 1987.

[37]. VYGOTSKY, L. S. **The collected works of L. S. Vygotsky, Vol. 2: The fundamentals of defectology (abnormal psychology and learning disabilities).** NY: Plenum Press, 1993.

[38]. VYGOTSKY, L. S. A defectologia e o estudo do desenvolvimento e da educação da pessoa anormal. **Revista Educação e Pesquisa,** *37*(4), 861-870, 2011. In: https://www.scielo.br/pdf/cp/v37n4/a12v37n4.pdf. Access: 03/02/2025.

[39]. ZENI, M. **Os cegos no Rio de Janeiro do segundo reinado e começo da república** [Doctoral dissertation, Universidade Federal Fluminense], 2005. In: https://app.uff.br/riuff/handle/1/1746