Astro Pi Mission Space Lab A Meta-review of Science Education Learning Materials

Katja Andersen & Frederic Conrotte
University of Luxembourg; Luxembourg Science Center

Abstract:

This meta-review analyzes and discusses the "Astro Pi Mission Space Lab" project and its potential for inclusive learning as perceived by five reviewers, consisting of three teachers, one prospective teacher, and one Astro Pi instructor. These five reviews were prepared based on the "Framework for the Reflection on Living Learning Materials" (FRoLLM), which is an evaluation tool focusing on the analysis of educational materials regarding their inclusion sensitivity, taking into consideration various learners' needs. This meta-review focuses on the research question of how inclusion and exclusion manifest in the context of the Astro Pi educational materials. Our analysis, based on the five reviews, shows that the Astro Pi materials are perceived as an inspiring initiative provided by European Space Agency (ESA) Education that not only captivates learners with the marvels of space exploration and coding but also offers a unique opportunity to assess and enhance learning materials in innovative educational contexts. At its core, the project combines theoretical science with practical application, as learners design and execute experiments using the Astro Pi computers aboard the International Space Station (ISS). This supports inclusion sensitivity in multiple ways, which are shown and critically discussed in this meta-review.

Keywords:

meta-review; Astro Pi; science education; inclusion sensitivity; FRoLLM evaluation tool

https://doi.org/10.11576/dilema-7894

1 Introduction

The evaluation of learning materials is essential for several reasons. It helps teachers determine whether resources meet the diverse needs of learners, accommodate varying levels of prior knowledge, and align with current educational standards. Open Educational Resources (OER) are learning materials that have an open licence, are accessible for everyone, and can be used free of charge (Kreutzer, 2016). This implies usage of the educational material as well as the implementation of changes and further development by its users (UNESCO, 2019). OER play a pivotal role in the success and accessibility of the "Astro Pi Mission Space Lab" project. The open access approach ensures that learners, educators, and teachers—regardless of their prior experience with space science, programming, or the design of experiments—can actively participate (Griffiths et al., 2022) and make meaningful contributions to the project. The evaluation of the Astro Pi educational materials—as well as of other OER-related materials—is of special importance for the impact on educational processes and outcomes since the underlying learning activities and projects build on the impetus to teachers that is made available online. Hence, the quality of the educational materials and their potential for activating learners' engagement with the OER content is decisive for learners' success in learning with these materials (Fischer et al., 2015; Crossfield & Ryan, 2022). This paper focuses on the evaluation of the Astro Pi educational materials with regard to their intentions and limitations to inclusion.

1.1 Introducing the Astro Pi Learning Materials

The digital learning materials discussed in this meta-review were created for the Astro Pi Mission Space Lab (ESA Education, 2024), which is an educational project created and led by the European Space Education Resource Office (ESA, n. d.) in collaboration with the Raspberry Pi Foundation (n. d.). This initiative offers pupils between the ages of 14 and 19 in all ESA member states the opportunity to design and carry out a scientific experiment on board the International Space Station (ISS), using specially adapted computers known as Astro Pis. The subgroup that leads this project in Luxembourg is called the European Space Education Resource Office Luxembourg (ESERO, n. d.), which is a joint project of the European Space Agency (ESA) and the Luxembourg Science Center (LSC), co-financed by the Luxembourg Space Agency and the Ministry of Education (Luxembourg Science Center, n. d.).

As a basis for our analysis, the framework of the Astro Pi materials is briefly outlined in this section. The goal of the Astro Pi Mission Space Lab is to have teams of two students each create a program that captures images of the earth from the International Space Station (ISS), with the intent of using this data to calculate the speed at which the ISS is moving at the time the images are captured. ESERO (n. d.) provides all the materials necessary to carry out this task, including a sample project with historical photos. The three-stage process of the Astro Pi Mission Space Lab is structured as follows. In a first phase, called "Experiment Design," the teams write their Python code, which is then subjected to rigorous testing by ESA to ensure functionality and safety. In the second phase, called "Space Deployment," approved projects are uploaded to the Astro Pi units on board the ISS, where they run autonomously under the supervision of astronauts. The third phase, called "ISS Evaluations," involves data analysis. Once the experiments are completed, the teams receive their data and analyze the results in order to draw conclusions about the speed at which the ISS is moving. The Astro Pi producers state that this three-step process ensures that the complex concepts of space science and technology are accessible while encouraging learners' critical thinking and problem-solving skills (ESA, n. d.; ESERO, n. d.).

https://doi.org/10.11576/dilema-7894

1.2 Brief Description of the Original Reviews

Our meta-review is based on five reviews of the Astro Pi learning materials that were created between October and December 2024. One of the reviews was written by a student in the *Bachelor en Sciences de l'éducation* (BScE) program at the University of Luxembourg, one by a primary school teacher, two by Luxembourg secondary school teachers, and one by an instructor in the Astro Pi program. The reviews were created on the basis of the reflection tool FRoLLM (Framework for the Reflection on Living Learning Materials; see Section 2) against the background of the following question: *How do inclusion and exclusion manifest in the context of the Astro Pi learning materials?* With a focus on this overarching question and based on the five reviewers' prior experiences with the Astro Pi learning materials, two of whom have not yet completed the third phase of implementation (prospective teacher and primary school teacher), not all questions of the FRoLLM catalog could be answered by all reviewers. Therefore, this meta-review does not claim to address all of the FRoLLM questions but aims to identify relevant inter-individual differences as well as striking similarities in the reviewers' assessments.

With this in mind, we aim to develop an idea of the extent to which inclusive potentials are contained in the Astro Pi materials and how further potential can be identified. A constraint that should be mentioned is that for a comprehensive analysis of the Astro Pi Mission Space Lab, the evaluation of the technical content (e.g., programming, data analysis, scientific investigation) would also have to be included. In our meta-review, however, we focus on the didactics and methods with which this technical content is conveyed, as well as on the overarching framework for implementing the Astro Pi materials in learning groups with pupils.

2 Methodology

This meta-review is based on the information provided by five reviewers who each independently evaluated the Astro Pi learning materials. The five reviewers were selected based on the following considerations. In order to receive feedback from different perspectives, a teacher in training and three fully qualified teachers were included in the review process. All teacher and student reviewers are female. The prospective teacher is a higher-semester student in the above-mentioned BScE study program at the University of Luxembourg. Two of the three experienced teachers work at the Luxembourg secondary school, the third is a primary school teacher. One of the secondary school teachers works at a technical secondary school, the other teaches at a general secondary school. In addition, one (male) instructor from the Astro Pi project in Luxembourg was involved in the review process.

The five reviews were created using the FRoLLM evaluation tool, which forms a viable basis for reflection on the "inclusion-sensitivity of educational materials, taking into consideration various learners' needs" (digiLLM, n. d.). The FRoLLM reflection tool consists of six areas, each of which encourages the reviewer to think about the learning materials from a different perspective: *Philosophy, Learners' Environment(s), Learners' Needs, Learners' Reflections on Learning, Learners' Agency,* and *Learning Feedback on Learning*. For each of these areas of reflection, the FRoLLM catalog contains two to five questions (20 in total; digiLLM, n. d.), which are illustrated using practical examples. The FRoLLM review process involves the reviewer firstly expressing their perception of the materials by awarding up to five stars for each question (quantitative feedback) and secondly writing a comment that supplements the quantitative assessment with further information (qualitative feedback).

Due to its clarity and the direct reference to teaching practice, FRoLLM was selected to create the five reviews on the Astro Pi learning materials. However, since reflection on questions such as "Does the material address the student as capable of mastering and controlling their own learning process?" (digiLLM, n. d.) requires full implementation of the Astro Pi materials into the teaching process and not all reviewers have yet completed the Astro Pi Mission Space Lab, some questions in the FRoLLM evaluation tool remained unanswered by individual reviewers. In order to synthesize the results of the five reviews, the meta-analysis approach of Cooper et al. (2013) was used, with a particular focus on identifying similarities as well as noticeable differences in the ratings of the five reviewers. We chose this approach for our analysis because it is particularly valuable when dealing with complex or heterogeneous data, such as reviews, where individual ratings may offer differing perspectives. By systematically collecting and comparing data from the five reviews, this approach allowed us to identify overarching patterns and effects across the reviews. To better systematize our analysis, we employed the six FRoLLM reflection areas (see above) to guide the identification of patterns related to the inclusion sensitivity potential of the Astro Pi materials. Comparing both quantitative data (ratings from 1 to 5 stars) and qualitative data (reviewers' written comments) allowed for a more comprehensive interpretation, facilitating the identification of common themes and insights that might not be apparent in individual reviews. Thus, the meta-analysis method proposed by Cooper et al. (2013) provided a rigorous and systematic framework for synthesizing our reviews, enabling us to draw more reliable and generalizable conclusions, particularly when comparing diverse data sources like reviewers' written comments.

We began by collecting relevant information from the five reviews with regard to our overarching research question. Subsequently, we systematically analyzed the content by coding it according to the six FRoLLM reflection areas—namely *Philosophy, Learner's Environment, Learner's Needs, Learner's Reflections on Learning, Learners' Agency,* and *Learning Feedback on Learning*—as outlined on the digiLLM project homepage (digiLLM, n. d.). The reviews were read and reread independently by the two authors until we had a comprehensive understanding of the aspects that would be pertinent for coding. We then assigned the reviewers' ratings to the FRoLLM reflection areas, integrating the findings into a cohesive set of insights. The interpretation of the evidence was guided by qualitative content analysis techniques, as described by Bengtsson (2016), allowing us to identify key themes and patterns in the data. Consequently, our meta-review does not aim to provide a comprehensive representation of all ratings but focuses on identifying salient similarities and differences between the reviews.

3 Analysis and Synthesis

Our analysis and synthesis are based on the five FRoLLM categories that are essential for understanding and enhancing the learning process with digital learning materials. The first category, *Philosophy*, focuses on perspectives on learning and teaching that, providing a framework for understanding how learning occurs in connection with the Astro Pi materials. The second category, *Learners' Agency*, examines how learners can take control of their own learning journey. This includes fostering self-regulation, motivation, and the ability to make informed decisions about their learning paths while using the Astro Pi materials. *Learners' Needs*, the third category, addresses the diverse and individual requirements of learners, encompassing cognitive, emotional, and social aspects. Understanding these needs is essential for tailoring educational approaches that support each learner's development while using the Astro Pi materials. The fourth category, *Learners' Environment*, explores the various contexts in which learning with the Astro Pi materials can take place, including physical spaces, social settings, and digital surroundings. Finally, *Learning Feedback to Learners* synthesizes the reviewers' views on how the feedback provided by the Astro Pi materials can help structure the learning process. This refers to providing timely, constructive, and clear feedback that guides learners in improving their performance and understanding. Together, these five FRoLLM categories form the framework for our analysis, which is grounded in the insights derived from the five comprehensive reviews of the Astro Pi learning materials.

3.1 Philosophy and Learners' Agency

Regarding the *Philosophy* of the material, all reviewers agree that Astro Pi has a good or very good structure and design (four to five stars), providing excellent opportunities for project teaching and learning as well as problem solving. The teacher from the technical secondary school emphasizes in her written comment that Astro Pi offers "plenty of online material to help the students […] to start and to complete the project" (Review 3), which in turn allows independent work and supports inclusion-sensitive learning. Specifically, this teacher sees Astro Pi as having great potential for inclusive learning in the STEM field since the materials are linked to "several other resources," such as GitHub[1], which supports possible "solutions and different tools" (Review 3). GitHub as a further resource is evaluated by all reviewers as very good or excellent, especially in regard to opportunities for individualized support. Consequently, one of the secondary school teachers rates the GitHub link as a very "effective collaboration tool" (Review 4) that allows learners to discover science content through diverse learning pathways. While both secondary school teachers point out that the "code is up to date" (Review 3) and that the Astro Pi Mission Space Lab allows students to investigate "a great set of computer knowledge around the Python language" (Review 4), neither the primary school teacher nor the prospective teacher refer to IT-related aspects in their written comments. One of the secondary school teachers, however, emphasizes that Astro Pi allows learners to "discover image processing" (Review 4, *Philosophy*) and makes them consider "other scientific parameters such as the curvature of the earth or the lens of a camera" (Review 4, *Learner's Environment*), thus allowing pupils to incorporate their individual imaginations and previous experiences (*Learners' Needs*).

In her comment on the FRoLLM reflection area for *Philosophy*, the primary school teacher considers it effective that the "Astro Pi learning material allows the teacher to provide additional impulses" when using the material in order to "optimally support the learners in their problem-solving process" (Review 2). The secondary technical school teacher critically evaluates the sheer number of options by noting that the "amount of guides" and information can sometimes be "overwhelming" and that it might be helpful to summarize the content and "provide a starting guide" (Review 3, *Learner's Agency*). All other reviewers rate the possibilities that the Astro Pi materials offer for realizing learners' agency as high or very high.

There are greater differences between the reviews when it comes to the question of whether the materials contain statements about the intentions and limits of inclusion (*Philosophy*). While the prospective teacher considers inclusion sensitivity to be "very present" (Review 1) in the Astro Pi materials, the primary school teacher feels that it is "not so strongly represented" (Review 2). In her comment, the primary school teacher justifies her assessment by explaining that the potential for inclusive learning and teaching is described "rather implicitly in the material" and that she thinks it makes sense to "express the intentions on the topic of inclusion more clearly in the Astro Pi material" (Review 2). Overall, however, the five reviewers' feedback regarding the usability of the Astro Pi material for inclusive teaching is very positive. For example, the individualization possibilities

[1] GitHub empowers developers to modify, adapt, and enhance software from its public repositories under various plans. This flexibility fosters collaboration and innovation within the open source community. The introduction of unlimited private repositories and unlimited collaborators for all users has removed previous limitations, allowing teams to manage their work together in one place. These enhancements provide developers with the tools and resources to innovate and contribute to the open source community.

(*Learners' Needs*) are rated as excellent (five stars) by all reviewers, a factor that the primary school teacher views as "important for the inclusion of all learners" (Review 2).

3.2 Learners' Needs, Learners' Environment, and Learning Feedback to Learners

It is striking that the assessments of the five reviewers show a particular agreement with regard to the factors relating to the *Learners' Environment*. For example, the teacher at the general secondary school points out that the Astro Pi learning materials facilitate "teamwork" in an excellent way by encouraging learners to "distribute tasks within their team, going as far as setting up and monitoring a schedule" (Review 4). The primary school teacher and the prospective teacher rate the potential for using the materials in various physical and digital learning settings as well as in "different kinds of group work" (Review 2) and "individual work" (Review 1) as very high. Particularly noteworthy is the reviewers' feedback on the question of the availability and free accessibility of the materials in various formats, which is rated as excellent by all five reviewers.

All reviewers agree that the materials contain opportunities for inclusion due to open access to technology. The teacher from the general secondary school states that thanks to the "tutorials" Astro Pi enables learners to (relatively) easily overcome the challenges associated with working on the task, helping them find solutions and "optimize the algorithm" (Review 4, *Learner's Environment*). In his written comment, the Astro Pi instructor explains that the project draws on "widely used technologies" (Review 5), such as the Raspberry Pi programming language and Python, which are "accessible tools that can be found or purchased inexpensively" and that, in turn, make participation "easier for schools and organizations with limited resources" (Review 5). Specifically, the Astro Pi instructor points out the comprehensive educational support from "ESA and the Raspberry Pi Foundation […] through educational materials, tutorials, and online resources" (Review 5). The Astro Pi online access, as described by the instructor, "democratizes access to knowledge" and allows pupils and teachers to learn "to code, design experiments, and analyze data regardless of their prior knowledge" (Review 5). The support options offered by ESA and the Raspberry Pi Foundation are consistently rated as excellent by all five reviewers.

With reference to the reflection areas *Learners' Needs* (including different learning paths) and Learners' Environment (including different types of groups), the Astro Pi instructor perceives the factors of international collaboration and multilingual resources as important for inclusion in the context of digitality. In particular, he considers the Astro Pi Mission Space Lab to be of outstanding importance because it is "open to learners in all ESA member states" (Review 5), supporting multiple languages and promoting international teamwork. This ensures, as the Astro Pi instructor states in his written comment, that language barriers are not an obstacle to using Astro Pi. In line with the instructor's assessment, the prospective teacher and the primary school teacher rate the Astro Pi materials as very good learning materials for all pupils, "regardless of their language skills" (Review 1). In her written comment, the primary school teacher even emphasizes that the "multilingual approach of the material is important for the inclusion of all learners" (Review 2), especially in the multilingual setting of the Luxembourg school system. Similarly, the teacher from the technical secondary school points out the international exposure of the Astro Pi materials, their excellent possibilities for both "self-organized work and working as a team" (*Learner's Environment*), the examination of "established coding standards," such as "failure tolerance, testing or storage usage" (*Philosophy*), and that there is "not one but many possible ways to solve a problem" (Review 3; *Learners' Needs*).

The ratings from the five reviewers are particularly high (four to five stars) in the area of *Learning Feedback to Learners*, emphasizing the advanced-level peer feedback that is provided by ESA. More critically, the instructor addresses aspects of the *Learners' Environment*, as Astro Pi requires "access to essential technology and the internet" (Review 5), but schools in low-resource areas may have difficulty obtaining Raspberry Pi units, sensors, or reliable internet connectivity for project development and data analysis. In his review, the instructor also considers the potential skill gap regarding coding and technical expertise, pointing out that some learners and/or teachers "may not have sufficient digital literacy skills to start working on the project" (Review 5, *Learners' Needs*), especially in "regions where computer science education at school is not well-established" (Review 5, *Learners' Environment*). This can exclude groups that are less familiar with programming and technical problem solving, as the instructor points out. Lastly, he reflects on accessibility barriers and states that some learners with special educational needs may find the Astro Pi project challenging, if the "educational materials and programming environments are not fully adapted to their needs" (Review 5, *Learners' Needs*). While ESA's efforts include basic accessibility considerations, specialized support for adaptive technologies or alternative learning formats could be expanded even further, the instructor concludes.

4 Discussion

Based on this analysis, it can be concluded that Astro Pi provides very good opportunities for learning in the STEM field of space sciences and technology. In line with the producers' statement (see Section 1.3), the five reviewers confirm that the three stages of the learning process with Astro Pi ensure that the complex concepts of space science and technology are accessible and stimulating, ultimately promoting the participation of all learners. Based on the analysis of the five reviews, it can be summarized that the Astro Pi project promotes teamwork and innovation while developing learners' coding, data analysis, and scientific research skills. Viewed from a content perspective, this is in line with ESA's mission to inspire and train the next generation of scientists, engineers, and space enthusiasts (cf. ESA Education, 2024). Furthermore, based on the reviewers' feedback, we can conclude that Astro Pi not only opens doors for content-related learning but also provides inclusive learning opportunities through individualized feedback for each learning group and hence supports learning on different levels and various learning paths.

If we look at the analysis from the perspective of the question of how inclusion and exclusion manifest in the context of the Astro Pi learning materials, two aspects must be taken into account. First, the factor of lowering barriers to entry needs to be addressed. The analysis of the five reviews showed that the Astro Pi project offers limited support options for pupils with special educational needs, such as blind or visually impaired learners. While the Astro Pi materials provide valuable resources like freely accessible guides, tutorials, and templates to support and challenge learners individually, their accessibility for blind and partially sighted learners is suboptimal. However, resources include step-by-step instructions for designing experiments, programming in Python, and understanding the hardware and sensors of the Astro Pi computers. This makes the project accessible for beginners and yet exciting for advanced participants.

This brings the second focus of the discussion into play, namely the promotion of equity and inclusion. By offering resources at no cost, the Astro Pi Mission Space Lab ensures that schools, youth groups, and communities with limited funding for STEM education can participate. The professional and free support from ESA, as emphasized by all reviewers, ensures that teachers without in-depth IT knowledge can fully participate in the Astro Pi project with their classes. In addition, the availability of the materials in multiple languages aims at the inclusion of all learners and is in line with ESA's goal of reaching students with different language competencies in its various member states (cf. ESA Education, 2024). The critical point to be made, however, is that individualized support for learners with special educational needs is not provided by the material. Yet, since the description of the Astro Pi materials does not indicate that it aims to actively support learners with special educational needs, this cannot be viewed as criticism of the materials but rather as an outlook for possible additions and future development.

In summary, with regard to inclusion and accessibility, the reviews show that there are two different perspectives on the Astro Pi materials. On the one hand, the reviews reveal the importance of access to the program being free and open to both the formal (e.g., secondary schools) and informal sector (e.g., youth organizations, afternoon childcare centers), so that learners from different educational institutions can participate. On the other hand, the aim of reaching out to as many young people as possible is supported by the fact that neither learners nor teachers need to have special prior knowledge regarding programming. Therefore, anyone interested can take part in the Astro Pi project and contribute according to their individual prior knowledge. This allows the participation of various learners at different levels of competence and offers incentives for both the learner with previous knowledge of programming and the learner who has never worked with this programming language before.

According to the reviews, the Astro Pi Mission Space Lab not only appears to empower pupils to engage with real-world science and space exploration, but the learning materials also seem to have the potential to instill a sense of wonder and curiosity about the universe. By conducting experiments aboard the ISS, pupils gain hands-on experience that bridges the gap between classroom learning and the latest in space science. It cannot be ruled out that using an analysis instrument other than FRoLLM might have revealed different results, as aspects such as appropriate grammar and terminology are not as prominently emphasized in FRoLLM as they are in other instruments for learning material evaluation (cf. Suartama, 2020). In addition, in order to better reflect the Astro Pi material, it is recommended to include a larger number of reviews and also to give a voice to pupils, both in primary and secondary school.

5 Conclusion

The Astro Pi learning materials provide a unique educational experience that allows young people to experience a real science mission and learn about the technologies used in space exploration. Through this project, pupils develop skills in programming, data analysis, and problem solving while exploring scientific concepts related to space motion and orbit. Overall, this meta-review shows that a systematic evaluation process provides valuable feedback that can lead to continuous improvement. By examining the impact of the materials on learners' educational processes and outcomes, teachers and curriculum developers can identify strengths, pinpoint areas for enhancement, and adapt strategies to better support learning. The reflection tool FRoLLM provides an important basis for such a systematic analysis process, allowing users to weigh in on the learning materials as well as the materials' producers and curriculum developers. Such an iterative feedback loop not only enhances learners' engagement and achievement in projects like Astro Pi but also contributes to the broader evolution of STEM education.

References

Cooper, H. M., Patall, E. A., & Lindsay, J. J. (2013). *Research Synthesis and Meta-Analysis*. SAGE Publications.

Crossfield, M., & Ryan, D. (2022). *Improving Student Success Through the Use of Open Educational Resources Introduction*. [White paper]. Yavapai College. https://www.wiche.edu/wp-content/uploads/2022/11/improving-student-success-through-oer.pdf

digiLLM (n. d.). *The FRoLLM*. https://digi-europe.org/frollm/

European Space Agency (ESA). (n. d.). *European Space Education Resource Office*. https://www.esa.int/Education/Teachers_Corner/European_Space_Education_Resource_Office

ESA Education. (2024). *The European Astro Pi Challenge 2024/25*. https://astro-pi.org

ESERO Luxembourg. (n. d.). *Das Weltall im Dienste der Bildung*. https://www.esero.lu/?lang=de

Fischer, L., Hilton, J., Robinson, T. J., & Wiley, D. A. (2015). A multi-institutional study of the impact of open textbook adoption on the learning outcomes of post-secondary students. *Journal of Computing in Higher Education, 27*, 159–172.

Griffiths, R., Mislevy, J., & Wang, S. (2022). Encouraging impacts of an Open Education Resource Degree Initiative on college students' progress to degree. *Higher Education, 84*, 1089–1106.

Kreutzer, T. (2016). *Open Content: Ein Praxisleitfaden zur Nutzung von Creative-Commons Lizenzen*. UNESCO.

Luxembourg Science Center. (n. d.). *Entdecken Sie unsere Projekte: ESERO Luxembourg*. https://www.science-center.lu/de/projects

Raspberry Pi Foundation. (n. d.). *Enabling all young people to realise their full potential through computing*. https://www.raspberrypi.org/

Suartama, I. K., Setyosari, P., Sulthoni, S., & Ulfa, S. (2020). Development of Ubiquitous Learning Environment Based on Moodle Learning Management System. *International Journal of Interactive Mobile Technologies, 14*, 182–204.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2019). *Guidelines on the development of open educational resources policies*. UNESCO.

Essay Information

Citation note:

Andersen, K., & Conrotte, F. (2025). The Astro Pi Mission Space Lab: A Meta Review of a Science Education Learning Material. *DILeMa, 1*(1), 62–71. https://doi.org/10.11576/dilema-7894

Available online: 28.08.2025