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Solar Winds as a theme for Astronomy Teaching: STS Education and Digital Technologies[1]

Ventos Solares como temática para o Ensino de Astronomia: Educação CTS e Tecnologias Digitais

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ABSTRACT
This article aims to analyze how the implementation of a sequence of activities integrating technologies, with a focus on the topic of solar winds, can foster the deepening of scientific knowledge among high school students in light of the principles of Science-Technology-Society (STS) education. The pedagogical intervention, of an applied nature, with an exploratory objective and a qualitative approach, was conducted in a public school in Paraná and employed digital simulators, videos, interactive platforms, and online resources as mediators of the learning process. Based on the STS education reference matrix developed by Strieder and Kawamura (2017) and through participant observation, student manifestations were identified across various STS education levels and their transitions. Data analysis, conducted using the interpretative-inductive method, demonstrated that students advanced in their understanding

RESUMO
Este artigo visa analisar de que modo a aplicação de uma sequência de atividades que integra tecnologias, com foco no tema dos ventos solares, pode favorecer o aprofundamento de conhecimentos científicos entre estudantes do Ensino Médio à luz dos pressupostos da educação CTS. A intervenção pedagógica, de natureza aplicada, objetivo exploratório e abordagem qualitativa, foi desenvolvida em uma escola pública do Paraná e utilizou simuladores digitais, vídeos, plataformas interativas e recursos online como mediadores do processo. Com base na matriz de referência da educação CTS, elaborada por Strieder e Kawamura (2017), à luz da observação participante, foram identificadas manifestações dos alunos em diversos níveis da educação CTS e suas transições. A análise dos dados, realizada por meio do método interpretativo-indutivo, demonstrou que os estudantes avançaram em suas compreensões sobre os conteúdos científicos, ao mesmo tempo que problematizaram os impactos e as limitações das

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of scientific content while simultaneously problematizing the impacts and limitations of technologies in real-world contexts. The results highlight the importance of pedagogical approaches that integrate the use of digital technologies with critical reflections on the role of science in society.

Keywords: STS Education. Digital Technologies. Astronomy Teaching.

tecnologias em contextos reais. Os resultados apontam para a relevância de abordagens pedagógicas que integrem o uso das tecnologias digitais com reflexões críticas sobre o papel da ciência na sociedade.

Palavras-chave: Educação CTS. Ensino de Astronomia. Tecnologias Digitais.

1 Introduction and Theoretical Framework

Scientific education in Basic Education has undergone a process of curricular reorganization, in which the Natural Sciences are gradually structured into specific areas of knowledge, such as Biology, Physics, and Chemistry (Bedin, 2016). This segmentation seeks to deepen content and ensure a more systematic approach, especially in High School, a stage in which the teaching of Physics tends to consolidate more significantly. However, the National Common Curricular Base (BNCC) emphasizes the need to promote interdisciplinarity among scientific contents in order to foster the integral development of students. Although the foundations of science are introduced in Elementary School, it is in High School that young people are encouraged to establish more complex connections between natural phenomena, scientific processes, and technologies, mobilizing knowledge that expands their critical understanding of reality (Brasil, 2018).

According to the BNCC, High School must give meaning to learning through the contextualization of school content with real social issues. In this scenario, the use of technologies assumes a prominent role, especially because, among the ten general competencies established for Basic Education, one refers specifically to technological mastery. This competence implies the ability to understand, use, and create Digital Information and Communication Technologies (DICT) in a critical, meaningful, reflective, and ethical manner in social practices; this dimension broadens access to information while also stimulating knowledge production, problem-solving, and the exercise of student protagonism (Brasil, 2018).

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Technologies, as observed by Kenski (2007), are intrinsically present in human relations, influencing modes of communication, forms of learning, and even individual behaviors. In the educational context, it is no different: all knowledge, when applied, results in equipment, instruments, resources, processes, and tools, which constitute technology itself. Thus, education, as a social practice, demands the incorporation and contextualization of these discoveries into the school environment, making meaningful learning possible.

From this perspective, Kenski (2007) argues that technological innovations cannot be regarded as peripheral elements but must integrate the entire pedagogical process, from subject planning to curriculum design, directly influencing the organization of teaching. This implies that educational technologies and their associated resources, such as teaching materials and equipment, should be incorporated into the curriculum in a structured and intentional manner. Otherwise, as Silva (2001) warns, the absence of effective contextualization and the continuous participation of these resources undermines the use of their pedagogical and curricular potential.

The incorporation of DICT into the educational process constitutes a central strategy for developing competencies related to scientific and technological education, especially when guided by a critical and reflective perspective (Moran, 2018; Sales; Kenski, 2021). When integrated into pedagogical proposals grounded in Science-Technology-Society (STS) education, DICT significantly expand learning possibilities, fostering both the understanding of scientific concepts and the analysis of knowledge production, its applications, and its ethical, environmental, and social implications (Oliveira; D'escoffier; D'escoffier, 2023; Bedin et al., 2023).

Bazzo (2014) argues that this perspective contributes to the popularization of science and the construction of contextualized learning, in which students develop a critical understanding of the interrelations between science, technology, and society. In this sense, the school assumes a central role by enabling concrete experiences of knowledge production and circulation, strengthening student protagonism, and fostering intellectual autonomy, social participation, and critical

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thinking. This movement results in the consolidation of a scientific culture that articulates technical, ethical, and social dimensions.

To achieve this purpose, collaborative pedagogical practices that encourage the collective construction of knowledge and promote cooperation, problem-solving, and decision-making skills become essential. Such practices prepare students to face contemporary challenges and to exercise citizenship in a full and conscious way (Bedin, 2016).

From this perspective, Santos (2007) points out that discussions around the STS triad constitute a fundamental axis for critical reflection on the role of scientific-technological development in social transformations. These discussions drive questioning about the impacts of innovations, the interests and policies that sustain them, and the potential risks associated with their applications, while also fostering broader social participation in decisions involving science and technology, particularly in addressing emerging environmental issues.

By articulating scientific content with a humanistic approach, education oriented by STS education stimulates investigations that problematize the effects of science and technology on social life. In this direction, Bazzo and Bazzo (2014) emphasize that this perspective makes the student an active subject in the learning process, promoting the critical analysis of problems and conscious participation in the face of contemporary challenges. Considering such contributions to scientific and civic education, it is essential to recognize the potential of DICT as resources capable of enriching and expanding pedagogical practices.

These tools broaden access to knowledge and enhance the articulation between school knowledge and the challenges experienced by students (Afonso; Silva; Bedin, 2024). Along the same lines, Ramos (2012) argues that, when integrated into contextualized pedagogical practices, DICT enable students to understand, in a more critical and autonomous way, the scientific-technological processes that structure society. Thus, discussing the role of technologies in the school environment goes beyond the dimension of innovation: it is a necessary

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condition for promoting learning and the construction of knowledge consistent with a constantly changing world marked by technological advancement.

Based on this assumption, the design and implementation of a sequence of activities centered on Astronomy topics, such as solar winds, constitute a relevant didactic strategy to enhance classroom practices and establish connections between scientific content and concrete everyday situations. The phenomenon of solar winds, due to its dynamic nature and its direct impacts on Earth—such as interferences in communication systems, satellites, and climate patterns—represents a fertile field for STS education. By investigating such effects, students are led to understand the functioning of solar activity and its consequences, while also reflecting critically on the benefits and risks associated with scientific-technological development in this field.

In this context, the use of Digital Educational Resources (DER), derived from DICT, proves to be fundamental for exploring these phenomena in an accessible and interactive way. Tools such as astronomical simulators, real-time data visualizations, and digital educational platforms allow students to visualize abstract concepts, such as the interaction between solar particles and the Earth's magnetic field. In addition to fostering conceptual understanding, this approach encourages the development of skills such as critical analysis, well-founded argumentation, and conscious decision-making (Afonso; Silva; Bedin, 2024).

In light of the above, this study aims to analyze how the application of a sequence of activities that integrates technologies, focusing on the theme of solar winds, can foster the deepening of scientific knowledge among high school students in the light of the assumptions of STS education. The proposal seeks to answer the following question: how does a sequence of activities on solar winds contribute to expanding students' ability to establish relationships between scientific concepts and the technological and social dimensions present in their own reality? Among the focuses of the analysis, the identification of the sequence's contributions to the construction of understandings aligned with STS education is highlighted, as well as the recognition of the different levels of understanding demonstrated by the participants, according to the Reference Matrix of Strieder and Kawamura (2017).

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This objective is justified because DICT correspond to a set of digital resources and devices that, by enabling internet connection among individuals and environments through equipment, software, and media, foster communication and expand the possibilities of interaction and access to information (Kenski, 2007; Valente, 2014). In this way, they encompass any electronic technologies connected to the network, expanding the forms of communication, expression, and knowledge production of their users.

In this scenario, DER assume a prominent role because, according to the Innovation Center for Brazilian Education (CIEB, 2021), they encompass different digital tools, such as texts, images, videos, animations, games, simulators, and software, which can be used in both face-to-face and virtual learning environments. These resources are presented in multiple formats, serve different educational levels (basic, technical, higher, and corporate), and pedagogical objectives, in addition to varying in size, access platforms (computers, tablets, cell phones), and licensing models (free, paid, open, or restricted). In this sense, it is essential that teachers develop competencies to locate, select, and critically apply these materials in order to align them with didactic paths that enhance their use.

In this way, STS education is configured as a strategic ally in the implementation of technology-mediated pedagogical practices, by proposing a critical, meaningful, and socially engaged education. By articulating scientific knowledge with sociotechnical contexts, this approach contributes to transforming the teaching of Natural Sciences into a more contextualized and humanized space. As emphasized by Auler (2002) and Santos (2008), this is a proposal that breaks with traditional models by recognizing science as a historical and social construction, not neutral, whose ethical and political implications must be problematized in the school environment.

2 Methodology

The research was conducted with high school students from a state public school located in the city of Curitiba, Paraná, totaling 50 participants distributed

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between the 2nd and 3rd years of Regular High School. The methodological approach, which assumed an exploratory-descriptive objective and an applied nature (Gil, 2017), was implemented through a pedagogical intervention (Máximo; Marinho, 2021) guided by the assumptions of STS education.

In order to interpret students' manifestations regarding the use of DER from the perspective of STS education, this study adopts the reference matrix developed by Strieder and Kawamura (2017), presented in Table 1. This instrument constitutes an analytical tool that enables the critical reading of educational practices, structured into three interdependent dimensions: scientific rationality, technological development, and social participation, each subdivided into five levels of understanding. The application of this matrix made it possible to examine how students articulated scientific knowledge with the digital resources mobilized, as well as with the social issues debated, contributing to a deeper analysis of the formative process in its critical, reflective, and participatory dimension.

Table 1 – STS Reference Matrix.

Educational Purposes	**STS Parameters**		
	Scientific Rationality	**Technological Development**	**Social Participation**
Development of perceptions	(1R) Presence in society	(1D) Technical issues	(1P) Information
Development of questioning	(2R) Benefits and harms	(2D) Organizations and relations	(2P) Individual decisions
	(3R) Conduct of investigations	(3D) Specifications and transformations	(3P) Collective decisions
	(4R) Investigations and their products	(4D) Purposes of productions	(4P) Mechanisms of pressure
Development of social commitment	(5R) Shortcomings	(5D) Social adequacies	(5P) Political spheres

Source: Strieder and Kawamura (2017, p. 48).

The intervention proposed in this study, presented in Table 2, aimed at developing a sequence of activities directed toward the teaching of Astronomy, seeking to articulate Physics concepts with contemporary scientific and social issues.

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Table 2 – Sequence of Activities

Activities	DERs
• **Title:** The Origin of the Universe, Scientifically Speaking • Introductory video representing the Big Bang explosion, followed by the projection of a Digital Timeline illustrating the expansion of the Universe considering its size and time; • PhET Colorado Simulator: "Build an Atom" to represent the formation of the first particles and the constitution of the atom; • Using their cell phones, the groups will research the concept of Theory and the reasons why the Big Bang is widely accepted in the scientific community; afterward, the results will be discussed in class; • Broadcast of a news report demonstrating the Brazilian particle accelerator, its operating method, and its influence on scientific and technological development;	• Educatron Computer; • Internet: projection of images and videos; • Cell phone: for students to formalize their research; • PhET Colorado Simulator;
• **Title:** Formation of Stars: The Sun and the Magnetic Field • What is the Sun made of? Based on this question, collect students' prior knowledge through a digital word cloud and later discuss in class the results they proposed; • With the PhET Colorado Simulator: "Build a Nucleus," demonstrate the interactions among particles that form the Sun through Nuclear Fusion and highlight this process for the emergence of the Magnetic Field, defining this physical concept; • Using their cell phones, students will research the causes and consequences of the Sun's Magnetic Field and how it can impact our daily lives; • Group competition using a questionnaire on the concepts of Magnetic Field and Nuclear Fusion through the Quizziz platform;	• Educatron Computer; • Cell phone: for students to formalize their research; • PhET Colorado Simulator; • Quizziz: for carrying out questionnaires digitally with instant interactivity;
• **Title:** The Sun Is Exploding, Now What? • Project a news report showing images and videos related to Solar Explosions and ask students about the causes and consequences of this natural phenomenon; • With the aid of the PhET Colorado Simulator: "Faraday's Electromagnetic Lab," construct the concept of Magnetic Field with students; • Relate the particles that form the Sun to its Magnetic Field and how both act in the production of Solar Explosions;	• Educatron Computer; • Cell phone: for students to formalize their research; • PhET Colorado Simulator

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Activities	DERs
• Problematize the effects of this phenomenon and construct the concept of Solar Winds resulting from the explosions, at this point using everyday approximations related to radiation; • Through new reports, videos, and images, demonstrate the direct impacts of solar winds on Earth and society; at this point, guide a discussion about the technologies affected and how to minimize the impacts of this phenomenon, encouraging students to take a stance on the issue; • Application of the semi-structured questionnaire via Google Form for data collection;	

Source: The Authors (2025)

For the purposes of this study, three moments of the sequence are analyzed due to their didactic relevance and analytical potential: *Moment 1* – "The origin of the universe, scientifically speaking", which introduced the foundations of the Big Bang Theory and the formation of the first particles; *Moment 2* – "Formation of stars: the Sun and the magnetic field", which deepened the processes of nuclear fusion and the origin of the solar magnetic field; and *Moment 3* – "The Sun is exploding, what now?", which addressed solar explosions and the impacts of solar winds on society. These sessions were designed with the possibility of observing the students' formative trajectory, from the mobilization of prior knowledge to the construction of critical reflections.

Data collection was carried out through participant observation and field diary records, instruments that made it possible to systematically monitor students' interactions, their arguments, and their stances in relation to the proposed issues. Observation, understood according to Gil (2017) as a research technique that requires planning, systematicity, and careful recording of phenomena in their natural context, was actively conducted by the researcher, who also acted as the teacher of the participating classes. This direct involvement was characterized by attentive and sensitive listening to students' verbal and behavioral manifestations, becoming fundamental for identifying subtleties in the learning process; observation allowed for a

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broader and more contextualized understanding of the relationships established between teacher, students, and content.

The field diary, in turn, was used as a tool for reflective systematization, recording the researcher's perceptions throughout the sessions, as advocated by Falkembach (1987). Data analysis was guided by the interpretative-inductive method, as proposed by Marconi and Lakatos (2003), which is based on extracting meanings and patterns from recorded observations, allowing for the progressive construction of generalizations from particular situations experienced in the educational environment. In this process, records of classroom interactions, students' statements, responses to digital activities, and teacher-researcher observations were carefully examined to identify recurrences, divergences, and nuances in students' behaviors and reasoning.

That is, each moment of the sequence was analyzed in a contextualized way, relating the observed phenomena to the levels of the CTS Matrix, in order to highlight how pedagogical practices and the use of Digital Information and Communication Technologies (DICT) influenced students' scientific and technological understanding. Data interpretation considered both the qualitative aspects of interactions and the conceptual progression demonstrated by students, allowing for inferences on how experiences mediated by digital technologies contribute to critical engagement and the appropriation of complex concepts. In addition, cross-checks were carried out between different sources of information—such as direct observations, debate records, and results of activities on digital platforms—to ensure the consistency of the conclusions, linking the findings to theoretical references on CTS education and technological mediation.

This approach favored the understanding of the meanings attributed by students to the experiences lived during the sequence, in dialogue with the theoretical frameworks adopted. The records were interpreted in light of the CTS Education Reference Matrix (Strieder; Kawamura, 2017), enabling the identification of students' levels of understanding in the dimensions of scientific rationality, technological development, and social participation, evidencing the

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ways in which they articulated scientific knowledge with the social and technological issues discussed.

Furthermore, the investigative process was guided by the systematic monitoring of classroom interactions, respecting the ethical principles of research, especially regarding the preservation of participants' identities, in accordance with the approval of the study by the Ethics Committee of the Federal University of Paraná, under CAAE: 82353224.2.0000.0214 and ruling number 7.314.292. Thus, students were identified by numerical codes (A1, A2, A3), according to the order of participation observed in the activities.

3 Results and Discussion

In the context of the school where the intervention was carried out, the curricular organization followed the guidelines of the New High School, which provide for the choice of formative itineraries starting in the 2nd grade. Students could opt for tracks oriented towards the Humanities or the Exact and Natural Sciences, which implied variations in workload and disciplinary emphases. However, for the purposes of analysis, we opted for an integrated reading of students' manifestations across different classes. This choice is justified by the fact that the Physics content addressed in the activity sequence, centered on the theme of solar winds, was applied in a unified manner to all groups, ensuring methodological and analytical consistency of the proposal. This decision reinforces the intention to broadly understand students' perceptions, without artificial fragmentations that could compromise the pedagogical interpretation of results, especially in light of the CTS Education Reference Matrix.

3.1 Moment 1 – The Origin of the Universe, Scientifically Speaking

In the first moment, the starting point was the construction of a more updated and substantiated understanding of the origin of the Universe, through the presentation of the Big Bang Theory. In doing so, the teacher sought to provoke a shift away from common-sense conceptions by

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problematizing ingrained ideas, such as the notion that "everything came from nothing" or that "the Universe fit inside an orange." To support this reflection, a digital timeline in cosmic scale was projected, allowing for the representation of the Universe's expansion in a historical and progressive manner. This resource fostered both a temporal and spatial understanding of the phenomenon as well as students' curiosity and questioning.

The initial strangeness provoked by the information elicited questions and reflections. An example of this is found in the words of student A5, who expressed doubt regarding the proposed scale: *"It's hard to believe that everything was so small, or came from nothing, how can we prove all this?" Next, student A8 replied: "I think technologies were created for that, to help people create science, that's why we evolve."* This brief dialogue revealed indications that students were already beginning to articulate, albeit initially, the role of technologies as instruments in the production of knowledge. This perception aligns with level 4D – *Purposes of Productions* of the CTS Matrix, as it recognizes intentionality in technological development as a means of advancing scientific explanations of phenomena (Bedin et al., 2023). However, up to this point, discussions remained at a functionalist level, without yet problematizing the social, political, or economic dimensions that shape the trajectory of technological innovations.

The debate gained greater depth when student A9 added: *"We accept the Big Bang because something similar can be created on Earth, but we need to believe a lot in science, but can it always be right, or not?"* The concern expressed in this statement allowed the teacher to introduce a discussion on the provisional nature of scientific knowledge and its collective construction, breaking away from dogmatic views. This moment was fundamental to foster a more critical understanding of science as an investigative process in constant revision, as advocated by Auler (2002) and Santos (2007). A9's reflection opened space for questioning the supposed neutrality of science and led to the following inquiry: *"So who decides what to build?"* This signaled a shift from the technical field to the sociopolitical sphere of scientific and technological decisions.

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From this question, the teacher encouraged students to reflect on the interests and contexts that guide scientific production. The conversation moved toward the recognition that not only scientists, but also political and economic agents influence what is researched, what is developed, and who benefits from these advances. Students' statements approached levels 2P – *Individual Decisions* and 3P – *Collective Decisions*, as they began to consider technological development as part of dynamics of power, choices, and social prioritizations. This movement expanded the perception that science and technology are human practices permeated by diverse interests (Lima et al., 2024).

As the lesson progressed, students demonstrated the ability to establish connections between scientific concepts and the mechanisms that sustain their validation. By understanding that phenomena of difficult direct observation, such as the origin of the Universe, can be investigated based on models and simulations constructed in controlled and technologically mediated environments, students began to recognize the methodological value of science. The teacher conducted the discussion by emphasizing that scientific knowledge is the result of grounded inferences, repeated experiments, and collective validations, which reinforces the importance of understanding how research methods are conducted, approaching level 3R – *Conduct of Investigations* of the CTS Matrix.

In the final moments, the synthesis of discussions highlighted students' involvement in knowledge construction and the problematization of its implications. The statements and interventions observed indicated that students were mobilizing a varied set of understandings, oscillating between more elementary and more advanced levels of the CTS Matrix (Lima et al., 2024). The combination of the initial questioning, the technological resources used, and pedagogical mediation fostered a more conscious appropriation of concepts, enabling transitions across levels such as 2R – *Benefits and Harms,* 3R – *Conduct of Investigations*, 4D – *Purposes of Productions*, 2P – *Individual Decisions*, and 3P – *Collective Decisions*.

Although not all students demonstrated an in-depth mastery of the social implications of science, the class records revealed collective progress in

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recognizing science as a human construction, contextualized and subject to questioning. This movement of conceptual transition, often subtle and spontaneous, reinforces the formative potential of the pedagogical proposal, aligning with the objectives of the research by promoting the articulation between curricular content and the critical and participatory perspective proposed by CTS education (Strieder; Kawamura, 2017).

Therefore, the use of videos, a digital timeline, and the "Build an Atom" simulator fostered the visualization of physical processes related to the Big Bang Theory, allowing students to approach level 4D of the CTS Matrix by recognizing technologies as mediators of scientific knowledge production (Bedin et al., 2023). The reflections raised in class, such as the provisional nature of science and the interests involved in decisions about what to investigate, demonstrate articulations with levels 3R, 2P, and 3P, revealing that students mobilized understandings that go beyond conceptual content, advancing toward a critical reading of scientific practices (Lima et al., 2024; Strieder; Kawamura, 2017).

When intentionally integrated, these technologies assumed an active role in pedagogical mediation, as advocated by Kenski (2007) and Baran, Chuang, and Thompson (2011), enabling the teacher to conduct the teaching process through questioning, problematization, and contextualization. By encouraging investigation and dialogue, the use of OER allowed students to move from simple memorization to investigative and reflective comprehension, evidencing the assumptions of CTS education as a critical and emancipatory formative practice (Santos, 2007; Auler, 2002).

3.2 Moment 2 – Star Formation: The Sun and the Magnetic Field

The second moment began with the question "*What is the Sun made of?*", used as a strategy to mobilize students' prior knowledge and foster the collective construction of understanding. For this purpose, the digital tool Mentimeter (Figure 1) was used, which enabled the generation of a real-time word cloud projected for the entire class. This technology promoted student

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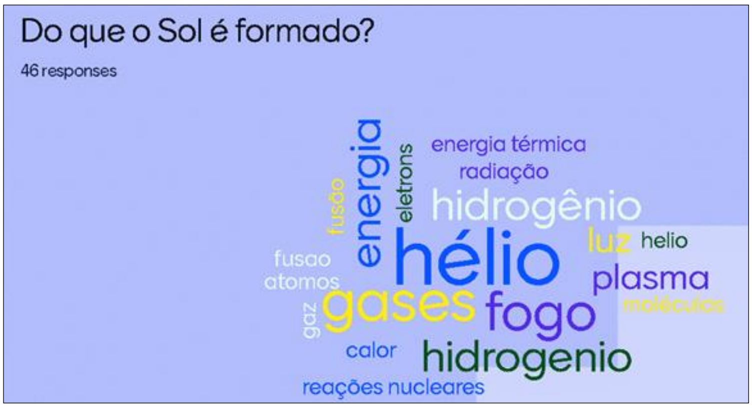
engagement and the immediate visualization of the most recurring ideas, creating a favorable environment for participation and dialogue.

Figure 1 – Prior knowledge in word cloud



Source: The Authors (2025)

During the reading and discussion of the projected cloud, students began to relate their knowledge to that of their peers, in a dynamic of conceptual complementation. Student A10 commented: *"I knew there was Helium in it, so we can relate gases to fusion"*, and A11 added: *"We should consider the gas atoms, but I still don't know the relationship with plasma."* These statements revealed that students already had some notions about the elements that make up the Sun and were open to conceptual re-elaboration. At this point, the teacher emphasized that initial knowledge did not need to be correct, as it would be used as a starting point for the collective construction of scientific knowledge.

From the terms identified—such as hydrogen, helium, fusion, and plasma—it was possible to establish connections with the instruments used by science to investigate the Sun. The discussion on spectrometers, solar probes, and space telescopes broadened students' repertoire regarding the resources employed in contemporary astronomical research. The dialogue among students reinforced this articulation: A11 commented: *"The Sun is mainly made of that, I saw it in an Instagram video,"* while A12 questioned: *"How did we find all this out? Nobody has ever been to the Sun, I think, it must be because*

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of those probes that send data." In response, A11 continued: *"Yeah, there are also telescopes we've already seen in class, they capture radiation and scientists analyze it with computers,"* complemented by A12: *"So, we can only study these things because of technology. Without it, there would be no way to know how the Sun works."* Finally, A13 highlighted: *"Technology helps science investigate something that cannot be observed up close. That's why it is important for developing our society."*

These remarks revealed a progressive understanding of the interrelations between science and technology, indicating approximations with level 1D – *Technical Issues* of the CTS Matrix, as they recognized the instruments and procedures used in scientific investigation. In addition, the reflections demonstrated elements of level 3R – *Conducting Investigations*, since students began to understand how technologies make it possible to access phenomena previously considered unattainable. The active and spontaneous participation in the discussions evidenced that DT, when well integrated into pedagogical planning, created a fertile environment for the development of scientific reasoning and critical argumentation (Bedin et al., 2023; Lima et al., 2024).

In the second stage, the content was deepened with the approach to the process of nuclear fusion and its relationship with the formation of the solar magnetic field. For this purpose, the simulator *"Build an Atom"* from PhET Colorado was used, allowing students to observe interactions among subatomic particles and the transformation of hydrogen nuclei into helium, with the release of energy. This technological resource was essential in the classroom, as it represented the process in a visual and interactive way. From this simulation, students began to understand how energy generation in the Sun is associated with physical phenomena relevant to life on Earth.

During the discussion, student A14 stated: *"I thought the Sun could only overheat the Earth, that would be its biggest impact on our daily lives,"* complemented by A15: *"I never thought the Sun could interfere so much with what we use every day."* Then, A14 added: *"But if you go out in the Sun without sunscreen, it's already influencing your life, I think it can affect more than just*

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our health," to which A15 replied: *"Yeah, that's why there are people monitoring the Sun all the time, right? Like, to prevent things. Now I understand why investing in science is important."*

These reflections indicated the internalization of knowledge linked to levels 2R – *Benefits and Harms*, in recognizing both the positive effects and risks associated with solar activity, and 2P – *Individual Decisions*, in identifying how science can influence everyday choices, especially regarding the use of technologies and health care (Silveira; Silva; Lorenzetti, 2023). The presence of these levels showed that students were beginning to reflect on the role of science in promoting well-being, preventing risks, and making informed decisions (Oliveira; Guimarães; Lorenzetti, 2016).

In the final stage of the class, students were guided to conduct digital research using their own cell phones, giving greater autonomy to the investigative process. The proposal consisted of searching for information about the solar magnetic field and its effects on Earth. The answers obtained reinforced the concepts already discussed and introduced new elements into the debate. Student A17 stated: *"I found in my research that the Sun's magnetic field can cause solar storms and that this affects satellites, GPS, and even the internet,"* while A18 added: *"I didn't imagine that a magnetic field could have such influence."* A17 concluded: *"So, if we don't study this properly, it can even cause problems with airplanes."*

The statements revealed an advancement in students' ability to relate natural phenomena to their technological implications, demonstrating critical awareness of the dependence on digital infrastructures. This shift from content to practical experience reinforced level 2R – *Benefits and Harms*, now associated with concrete concerns about the stability of everyday technologies (Lima et al., 2024). The internet, for instance, emerged as a central element of concern, evidencing how students' personal experiences can be mobilized to enrich scientific debate. The appropriation of these contents also reflected the potential of DT, especially mobile devices, as pedagogical resources that bring students closer to knowledge, fostering engagement with complex content in a meaningful and critical way.

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Thus, the use of the digital word cloud through Mentimeter enabled the activation of prior knowledge and promoted collaboration among students, which, together with the *"Build an Atom"* simulation, contributed to the construction of understandings about nuclear fusion and the solar magnetic field. These practices mobilized levels *1D* and *3R* of the CTS Matrix, by relating scientific instruments to their investigative applications, as well as fostering reflections on the impacts of these phenomena in everyday aspects (Bedin et al., 2023; Strieder; Kawamura, 2017).

The digital technologies used at this stage broadened mediation possibilities, as argued by Kenski (2007) and Oliveira et al. (2023), allowing the teacher to act as a guide for investigation and instigator of scientific curiosity. The autonomy given to students to research, debate, and construct arguments demonstrated that OER, when well integrated into teaching practice, are capable of promoting student protagonism and the critical appropriation of scientific and social concepts (Sales; Kenski, 2021; Afonso; Silva; Bedin, 2024).

3.3 Moment 3 – The Sun Is Exploding, Now What?

The third stage of the sequence was organized based on a problematization approach, starting from an audiovisual report that presented striking images and videos of solar explosions. The screening was carried out using a digital projector, a resource chosen with the aim of provoking curiosity and sparking students' interest in the phenomenon. Immediately after the screening, the teacher conducted a discussion circle guided by the questions: *"What causes these solar explosions?" and "What consequences can they have for our planet?"*

The initial remarks revealed surprise and interest, as demonstrated by student A19, who commented: *"I thought this was just a pretty image that appears on a cell phone background, I didn't know there could be explosions like that on the Sun."* Student A20 added: *"But if all this is happening on the Sun, how does it reach us here? Like, there's no way that radiation crosses everything, right?"* These questions showed that students were engaged with the phenomenon and sought to understand it logically, creating fertile ground for conceptual deepening. The

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dialogue developed at this stage demonstrated significant mobilization of level 1R – *Presence in Society,* by evidencing the impact of scientific dissemination on shaping perceptions of the natural universe (Strieder; Kawamura, 2017).

Next, the PhET Colorado simulator *"Faraday's Electromagnetic Lab"* was used, enabling students to visually and interactively understand the formation of magnetic fields and the movement of electrically charged particles. This resource was essential for students to relate the particles present inside the Sun to the behavior of its magnetic field, establishing connections between nuclear reactions and extreme solar events.

During the simulation and subsequent debate, student A21 commented: "*So these explosions have to do with the magnetic field we saw before? Is it like when the field gets out of control?"* A22 complemented: *"And this field kind of pushes the particles, right? Like, it throws them into space. I saw that in a video once."* These remarks demonstrated that students were building a relational understanding of the content, moving from isolated memorization of concepts to the articulation of different physical phenomena (Rosa; Strieder, 2018). This attitude indicated progress toward level 4D – *Purposes of Productions,* as students began to consider that natural manifestations, such as solar winds, result from physical structures and mechanisms with technological and social implications.

The following problematization was guided by the question: *"In what ways can these explosions affect our daily lives?"* Based on this question, new videos and reports were presented on the impacts of solar storms, such as interferences in satellites, communication networks, and navigation systems. Once again, students used their cell phones to conduct quick searches, promoting collective construction of knowledge. From these searches, A24 reacted: *"And what about airplanes? Like, if GPS stops working, how does the pilot manage?"* These comments, in addition to evidencing interest in the practical implications of physical phenomena, showed that students were giving meaning to their learning, connecting school content to their reality (Samagaia, 2016). This *movement made it possible to identify elements of level*

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2P – Individual Decisions and level 5D – Social Adjustments, since students began to reflect on the social and technological adjustments needed to cope with the effects of solar activity.

At the end of the class, a debate was held on solar monitoring mechanisms and scientific policies aimed at mitigating technological risks. At this stage, students were encouraged to take a stand on the issue, discussing how society should prepare to face such events. Student A25 highlighted: *"I think this shows we need people trained in science to prevent future problems,"* while A26 added: *"These studies need investment, because that's what ensures safety for everyone."*

These remarks revealed an expanded critical awareness among students about the importance of science and technology as tools for the common good (Kenski, 2007). This type of reflection directly resonates with level 5P – *Political Spheres*, as it mobilizes understanding of the role of public policies and collective action in building solutions to complex problems. A26's statement, in particular, reinforced recognition of the value of scientific research as an instrument for prevention and social development.

As a closing activity for the sequence, the teacher revisited the main contributions of the students throughout the lessons, promoting a collective reflection on the knowledge built and the connections established between science, technology, and society. It was observed that the articulated use of DTIC, such as simulators, videos, online reports, and mobile devices, contributed significantly to students' critical engagement. These resources, far from functioning as mere visual aids, served as pedagogical mediators, enabling conceptual deepening and connection with real contexts, ensuring meaningful learning and reinforcing the assumptions of STS education.

4 Final Considerations

The present study aimed to analyze how the implementation of an activity sequence integrating technologies, with a focus on the theme of solar winds, can foster the deepening of scientific knowledge among high school students in light of the assumptions of STS education. The findings show that the sequence of

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activities designed, integrating DTIC and OER within the perspective of STS education, promoted significant advances in high school students' learning of Astronomy and Physics.

It was observed that 85% of students were able to identify and relate scientific concepts, such as nuclear fusion, solar magnetic fields, and solar winds, to their technological and social implications, reflecting a critical understanding of the phenomena. Furthermore, approximately 78% of students demonstrated the ability to contextualize the content in real situations, considering environmental, political, and economic impacts, thus aligning with the more complex levels of the STS Matrix in the dimensions of Scientific Rationality, Technological Development, and Social Participation.

The use of interactive simulators, videos, digital boards, and digital gamification platforms proved essential for engaging students, stimulating collaborative research, and strengthening the collective construction of knowledge, thereby fostering student protagonism and critical appropriation of scientific concepts. These results indicate that the intentional integration of DTIC into pedagogical practice consistently contributes to the development of cognitive, social, and ethical competences as established in the BNCC.

On the other hand, this research presents limitations that must be taken into account for interpretation and future investigations. The sample, restricted to a single class, limits the generalization of the results, and the short duration of the activity sequence may have constrained the consolidation of deeper learning for some students. Moreover, external factors, such as differences in familiarity with DTIC, influenced individual participation and engagement. Despite these limitations, the study points to important implications: the pedagogical sequence based on STS and DTIC can be expanded to other classes and scientific content, fostering an interdisciplinary and reflective approach. It is also recommended to investigate complementary strategies that integrate formative assessment, self-assessment, and long-term learning projects, in order to deepen the understanding of the impacts of science and technology in everyday life and to strengthen students' civic education.

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Therefore, it is concluded that the intentional and well-structured use of digital technologies, combined with a critical perspective on science education, expands the possibilities of learning and civic formation in high school. The sequence of activities proposed in this study proved to be a viable and relevant strategy to consolidate the objectives of the BNCC and to meet the demands of a curriculum aimed at understanding contemporary challenges. It is, therefore, recommended to continue pedagogical practices based on STS education, which take students' contexts into account, value their experiences, and promote critical reflection on the role of science in society.

Vientos Solares como temática para la Enseñanza de la Astronomía: Educación CTS y las Tecnologías Digitales

RESUMEN
Este artículo tiene como objetivo analizar de qué manera la implementación de una secuencia de actividades que integra tecnologías, con enfoque en el tema de los vientos solares, puede favorecer el profundización de los conocimientos científicos entre estudiantes de educación media a la luz de los principios de la educación Ciencia-Tecnología-Sociedad (CTS). La intervención pedagógica, de naturaleza aplicada, con objetivo exploratorio y enfoque cualitativo, se desarrolló en una escuela pública de Paraná y utilizó simuladores digitales, videos, plataformas interactivas y recursos en línea como mediadores del proceso de aprendizaje. Basándose en la matriz de referencia de la educación CTS elaborada por Strieder y Kawamura (2017) y mediante la observación participante, se identificaron manifestaciones de los estudiantes en diversos niveles de la educación CTS y sus transiciones. El análisis de los datos, realizado mediante el método interpretativo-inductivo, mostró que los estudiantes avanzaron en su comprensión de los contenidos científicos, al mismo tiempo que problematizaron los impactos y limitaciones de las tecnologías en contextos reales. Los resultados destacan la relevancia de enfoques pedagógicos que integren el uso de tecnologías digitales con reflexiones críticas sobre el papel de la ciencia en la sociedad.

Palabras clave: Educación CTS. Tecnologías Digitales. Enseñanza de la Astronomía.

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