

Science in Anime? A Debate from the Content and Characteristics of Communication of Science-related Ideas

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ABSTRACT

To investigate the content and characteristics of the communication of science-related ideas in anime, this work examined six productions of worldwide popularity. Fleck's epistemology was employed as theoretical background to understand the communication of ideas. The first 50 episodes of each anime (except for two that comprised 35 and 21 episodes at the time of the research) were watched, and all the excerpts containing terms, expressions, or representations referring to science were identified, transcribed, and coded. The overall results indicate the strong presence, both unintentional and intentional, of representations of science (396 scenes), most of which are scientifically accurate (377) and combine visual and verbal texts to display mentions or explanations. The set of anime analyzed demonstrates a potential role for the exchange and the furtherance of intra- and intercollective interaction of scientific ideas, as well as for discussion between specialized, school and popular audiences.

KEY WORDS: Epistemology, Ludwig Fleck, media and science, science communication

INTRODUCTION

Interest in anime has intensified around the world, giving rise to social groups that establish modes of communication, clothing and behavior with their own meanings, forming cultural "tribes" that share the consumption of content and products arising from Japanese pop culture (Gonçalves et al., 2021; O'Hagan, 2007; Yamato, 2016). Anime then became part of a complex popular media arena that includes books, movies, comic-books, Internet, videogames, among others. With the advent of the Internet, this cultural universe expanded even more dramatically through virtuality, turning into a transcultural process (Cooper-Chen, 2012).

As a consequence, the academy has focused investigations into the universe of anime, covering a diversity of areas of knowledge and themes, which include natural sciences and its representations. Ryu et al. (2020) discussed possibilities for teaching physics through the analysis of anime, highlighting excerpts, processes, and terms that can be retrieved and put up for debate. The authors focused on the theme of fluid mechanics, concentrating on popular anime in the United States (Pokémon, Yu-gi-oh, Dragon Ball, and Naruto). The works of Campos and Cruz (2020) and Alfina et al. (2024) focused on the anime *Hataraku Saibou* (Cells at Work, in English), highlighting its relationship with biology. They emphasize anime as an entertainment culture that is part of a widely popular dimension. In such perspective, James (2020) investigated conventions, events that bring together increasing numbers of people who share an interest in themes specific to

this culture. The author argues that such conventions become a means of scientific dissemination by focusing the discussion on concepts and phenomena, which include representations of science and science fiction. James (2020) states that the debate about science is part of the experience at the convention, integrated into the discussion about anime.

Professionals from science areas also attend such events, either as participants interested in anime or as guests invited to contribute to discussions (Childers et al., 2023). Some of these conventions provide sessions in which science professionals share their knowledge of science related to science fiction and fantasy with the audience (Childers et al., 2023). Although unintentionally, anime has triggered relationships between science and society from a historical and sociocultural perspective.

As a popular cultural medium, anime can also shape public perceptions about science due to its plausibility, a certain degree of verisimilitude, and entrusted scientific authority of the plot, like other cultural media resources (Van Riper, 2003; Barnett et al., 2006; Tan et al., 2017). Plausibility refers to ideas that may appear valid or feasible to a general audience based on its previous scientific knowledge and the information presented in the plot. Verisimilitude pertains to the accuracy of scientific ideas. In this way, combining visualization with character-driven narratives, popular media provide a kind of scientific authority that can blur the lines between fact and fiction. In so doing, misunderstandings may emerge or be supported by representing fictional and multiple perspectives of

science (Locke, 2005). Moreover, graphics and non-scientific information may be more attractive to the audience. Thus, anime can promote or reinforce simplistic views by means of the enjoyable characteristics of such media (Mahler and Mayer, 2024). From such a perspective, scientific assumptions should be evaluated to determine their accuracy based on criticisms about detected errors and/or ambiguities (Barnett and Kafka, 2007; Tan et al., 2017).

Conversely, popular cultural media must be considered far beyond their incorrect representation of science or as non-science, but as a complex cultural arena in which science is represented (Kirby, 2008; Locke, 2005). In this regard, there is an interest in understanding the communication of science-based content in such products, since anime is widely watched by different audiences and is present both in non-school spaces (Childers et al., 2023) and in schools as teaching resources (Alfina et al., 2024). However, one can assume that studies focusing on anime and how they address science-based ideas are scant. These aspects led to the formulation of the following question:

- RQ: Which representations of science are portrayed through anime?

Seeking to answer this question, this study analyzed the content and characteristics of the communication of science-based ideas in anime. To this end, the work is supported by Ludwik Fleck's epistemology, especially in his themes on the formation of thought collectives and the communication of ideas within or between collectives, as well as on science communication through popular media.

Fleck's Epistemology and Science in Popular Cultural Media

Polish doctor and philosopher Ludwik Fleck (1896-1961) conceived a theoretical framework that enables to ponder about the development of science, its process of communication, and relations with society. Albeit recognized belatedly, his ideas can be seen as pioneers in the analysis of the history, philosophy, and sociology of science (Carifio and Perla, 2013, Martins, 2016). Studying the production of knowledge about syphilis, Fleck created a theoretical framework that perceives scientific thought as a collective construction of a community that shares certain forms of thought. According to Fleck (1979, p. 38): "Cognition is therefore not an individual process of any theoretical 'particular consciousness.' Rather, it is the result of a social activity, since the existing stock of knowledge exceeds the range available to any one individual." This way of thinking within a given social group was called a thought style. The thought style is accompanied by specific characteristics of the given social group. This group, specialized in a specific scientific field, sharing common language, concepts, methods, and other characteristics, constitutes a collective thought, which works in knowledge production. Professionals who share the same styles, setting up or orbiting around thought collectives, in turn form the esoteric circles of a given field.

Such circles are subject to the influence of historical, political, and social contexts in the construction and reconstruction of "thought collectives" and "thought styles." From this perspective, theoretical, experiential, and empirical constructions occur in the sharing of groups, influenced by contexts, which come together for the process of knowledge construction. As a collective activity, science involves debates and disagreements, and is not consensual, presenting provisional and relational answers rather than absolute ones (Fleck, 1979).

Influenced by these thought styles, the collective produces knowledge. When this knowledge is communicated within the same collective, or the esoteric circle, it triggers an intracollective communication of thoughts and practices. At the same time, these terms, notions, debates, and explanations can enter other spaces and reach other groups of non-specialists. The latter constitute exoteric circles. On moving between them, they promote the flows of ideas and concepts and generate mutual transformations of these styles. What Fleck called intercollective communication of ideas emerges, contributing to modify, (re)direct or even discard thought styles.

Fleck (1979) also points out that there is a certain differentiation between types of knowledge, which are formed based on language, audience, and modes of communication between smaller or larger groups, more restricted or with greater reach.

This differentiation occurs based on the notion of "sciences," and distinguishes between: (1) journal science for the special experts, (2) handbook science for the general experts (*vademecum*), (3) popular science for the exoteric circle, and (4) textbook science for initiation into the esoteric circle. Intracollective or intercollective communication occurs in a distinctive way in each of these "types" of science. Through the science of journals, there is a more restricted communication aimed at individuals of the same esoteric circle and who constitute the same thought collective. Handbook science is also a constituent of specialized science, but it differs in that it is aimed at training specialists, such as new researchers in a field or professionals who make technical use of scientific information.

More emphatically, Fleck presents popular science, which comprises broader and more diverse channels of knowledge exchange, with a view to making it part of the repertoire of discussions of a general population containing a wide range of exoteric circles, in dialogue with individuals from esoteric circles who are engaged in the process of communicating science.

This can lead to the assumption that anime is also a cultural arena that unites "expert" and "non-expert" alike. At the same time, anime acts as metaphorical and multiple representations of science rather than as proper scientific knowledge, as discussed by Fleck. Despite this characteristic of a metaphorical representation of science, popular media may question the role, relevance, costs, and benefits of current and future knowledge

and technologies (Menadue and Cheer, 2017). Therefore, these representations of science serve as a bridge between human imagination and scientific principles and can influence public thought and opinion about the affordances of scientific endeavors (Menadue and Cheer, 2017).

Locke (2005) argues that the representations of science address questions about the social and cultural meanings of science that are constituted of the same basic principles as academic concerns. Thus, when science aspects are inserted into cultural products such as anime, there is an exchange of ideas, which affects the reach of science to different audiences. This is in accordance with the diversity of arenas between the public and experts in exchanging ideas pointed out by Fleck. Consequently, these representations are entangled with a range of characteristics of science by providing different ways of thinking. Anime thus encompasses a popular and complex representation of science. In this context, one can assume that popular science and popular cultural media are intertwined.

This perspective cannot simply assume accuracy of representations of science as good and the failures as harmful to the public understanding of science. This gives to raise a kind of tension. For instance, Orthia et al. (2012) obtained contradictory results in an investigation of university students' perceptions of a science-rich episode of the Simpsons. Some participants did not recognize science at all in the episode, while others highlighted science as an ideological focus. Thus, science in popular narratives can enable alternative modes of knowing to embody fictional and factual debate or even go unnoticed. Rose (2003) argues that even fictional representations, when plausible, are thought-challenging because they make people wonder whether fictional science is possible. Based on this general framework, this paper focuses on both the representation of scientific content and the modes of communication in anime.

METHODOLOGY

This study analyzed the communication of science-based knowledge in anime of worldwide dissemination. To this end, a qualitative-interpretive perspective was employed, which is concerned with the description and understanding of processes (Bogdan and Biklen, 1998). The interest relies on the scientific content based on images and speeches contained in anime, which is complex and little known. The first step was to select the anime to be investigated. A number of criteria were used to select anime in this study. The criteria had to: (i) portray science and scientists in action; (ii) rank among online forums specialized in Japanese culture; (iii) to be available on open TV (in Brazil) or worldwide streaming channels.

In terms of science portrayal, the previous experience of the researchers as anime fans and science teachers gave rise to six productions, three in which science is central throughout the plot (Dr. Stone, Full Metal Alchemist and Cells at Work), and the other three in which science can be identified in different episodes. Although scanty, a review of the literature revealed

previous studies that had identified scientific correlations for all these six productions (Alfina et al., 2024; Dietrich et al., 2021; Gonçalves and Alves, 2021; Peiro Agustín et al., 2021; Ryu et al., 2020). A free search was carried out on social media and online platforms to evaluate popularity. Dragon Ball, Pokémon, Naruto, and Full Metal Alchemist consistently appeared as very popular. The first three are ranked as the most popular anime in the world (Tilakaratne et al., 2024). In Brazil, Dragon Ball, Pokémon, and Naruto have been broadcast on TV for at least 20 years. A search using anime and science on online platforms and social media indicated that scientific content has been recognized and debated by fans from Dr. Stone, Full Metal Alchemist, and Cells at Work. Lastly, all of them were available on streaming channels. The set of anime was accessed via the streaming platforms <https://www.netflix.com/br> and <https://www.crunchyroll.com.br>, and watched in Japanese with subtitles in Portuguese.

To define the analytical material, the initial 50 episodes of each anime were established, except for Dr. Stone and Cells at Work, which at the time of the research, comprised 35 and 21 episodes, respectively. Data were collected using documental analysis with descriptive recording of information in a paper notebook. The selected episodes (average duration of 20 min) were watched in full and examined following the principles of content analysis (Bardin, 2011). The steps of content analysis included familiarization of data, selection of the unit of analysis, generation of codes, generation of categories, and production of a descriptive and interpretative report (Bardin, 2011). Initially, each episode was watched primarily by the first author, and all associations with science were recorded. The episodes were watched at least twice for the initial gathering of information, aiming to ensure its validity. All the excerpts containing terms, expressions, or representations referring to science were identified, and the number and title of the episode, minutes and seconds of the identified excerpt were recorded using a text editor program. Next, images were captured, speeches transcribed, and scenes described, constituting the corpus data. This step provided an overview of the unities of analysis in terms of the number and frequency of representations of scientific content.

After establishing the corpus, the procedure continued with the codification and categorization steps. An approach to coding data by using qualitative content analysis typically begins by identifying units of meaning in the text, condensing them into smaller units, and then labeling these units with codes (Bardin, 2011). In this process, the synthesized information was read in full, detachedly and separately by two researchers. Each of them assigned codes to the scenes based on the semantic and scientific meanings of the identified expressions/terms. After determining all the codes, the units were read in full again to verify their accuracy and ensure the saturation of emergent codes had been reached. After both investigators independently checked for saturation, the codes were discussed to identify which ones could be assembled into broader categories.

To increase reliability, this step was carried out jointly by two researchers. Both the coding process and theme development were iterative and reflexive. The researchers worked collectively to constantly question and check assumptions and interpretations against the data to consensually define categories and subcategories, if applicable, and employed deductively to refine and reduce data inconsistencies. Discrepancies were addressed by reexamining the data and crosschecking them against previously established consensual interpretations.

This procedure resulted in two major groups of representations of scientific content: (i) representations of scientifically accurate content (use of expressions and ideas that come close to scientifically accepted concepts); and (ii) representations of fictional or fantasy content (expressions and ideas that are referred to in science, but that are used as fictional or fantasy representations). Table 1 exemplifies units of meaning (scenes), codes, and the primary categories constructed in the initial moment.

After this initial codification and categorization, the process was repeated with a focus on the modes of communication (textual - written/verbal, visual) of science representations,

that is, basically the resources used to present the information. The modes of representation were analyzed based on verbal and visual content, aiming to ascertain the context in which scientific ideas and expressions appeared, the level of detail (whether they are mentioned superficially or in greater detail), and the use of verbal and visual language. Thus, the visual content was analyzed in terms of images of scenes before, during, and after the representation of scientific content, leading to the construction of subcategories. Table 2 exemplifies this process for scientifically accurate content representations.

Two subcategories were created for scenes encoded as representations of fictional or fantasy content, as described in Table 3.

After this, the subcategories were quantified to evaluate their representativeness within the set of anime. The results were presented considering such quantitative elements, but fundamentally descriptive-interpretive qualitative aspects. Fleck's (1979) concepts were used for this purpose, as well as works that consider the relationship between science and popular cultural products.

RESULTS AND DISCUSSION

The selection of passages referring to science in the anime examined here resulted in a large number of records. Table 4 lists the number of contents represented with scientific accuracy and in fictional or fantasy form, with their respective subcategories.

Firstly, there is a greater representation of science content of a scientifically accurate or unproblematic nature in terms of meaning, contained in all the anime, mostly in the form of mentions. Fictional or fanciful representations emerged to a lesser extent, with those in which fictitious or fantasy ideas are presented with some approximation to scientific logic prevailing. The presence of scientific content at various times indicates that science communication processes are inherently present in anime.

The presence of science is more significant in three anime. In the case of *Dr. Stone* and *Cells at Work*, science plays a pivotal role in the plot. In *Full Metal Alchemist* and *Dr. Stone*, the main characters take on the role of scientists. In turn, although *Pokémon*, *Naruto*, and *Dragon Ball* are not necessarily about science, their consistency in the plot occurs in different ways. There are characters who clearly appear as scientists developing specific studies and who use technical language typical of a thought collective. In *Pokémon*, for example, esoteric circles are created analogously to scientific knowledge, since the study of these creatures is a field of scientific knowledge in the anime's plot, with research centers, specialized journals and conferences. This can be seen as a representation of the concept of community and collective construction of knowledge in Fleck, which promotes the communication of practices and habits specific to the scientific community. Although Fleck

Table 1: Codes and categories constructed for the type of representation of scientific content

Transcription/description of the scene	Codes	Category
Chrome: – Maybe I can dissolve it using sodium hydroxide. These cables shouldn't be that strong. I have electricity. And I only need seawater. Senku used seawater, but I won't get it in prison. So, my only choice is to make seawater! (The character uses sweat)	Researcher 1 Adequate terms Scientific rigor Researcher 2 Conceptual rigor Accuracy of terms	Scientific accuracy
Dr. Stone, ep. 06, 13m 10s		
Improve radio waves to induce Pokémon to "evolve." Pokémon, ep. 237, 6 min 39s	Researcher 1 Term with correspondence in science Fantasy process Researcher 2 Existing term Does not follow scientific principles	Fictional/fantasy
I'll explain it in a simple way so that you can understand. Chakra is the elemental energy of life that a ninja uses in jutsu. It is the source of all his power. This energy has two forms: Physical energy, which exists in all the cells of the body which work together. And spiritual energy, the primal source of power, which is intensified through training and experience. Naruto, ep. 10, 11 min 15s	Researcher 1 Fantasy idea Association with scientific concept Scientific rhetoric (explanatory) Researcher 2 Fictional idea (Chakra) Related to science (energy)	Fictional/fantasy
Source: Research data		

Table 2: Main characteristics of the categories

Categories	Characteristics of representations		
Mentions	Scientific terms are mentioned in the characters' speeches	The processes or structures studied by the sciences mentioned are not correlated to the context of the anime	The scenes continue without further detail or recursiveness with respect to the expressions/ideas mentioned
Example	"This water isn't normal. It's dense, heavy." Naruto, ep. 08, 6 min 25 s	This speech occurs during a fight, when one of the characters is thrown into the water. The comment is made upon feeling the difference in property compared to what you are used to (normal).	As the scene continues, the fight goes on with no further development of the scientific idea.
Explanations	In addition to the quote, ideas or expressions are described	The context of the plot establishes relationships with the representation of scientific content	The scenes continue with details of the ideas/expressions, such as examples, associations or cause/effect relationships. In some cases, other resources are mobilized (analogies, schemes) that emphasize the representation of the concept
Example	"The vibrations of molecules in the air create a sound wave. These vibrations are picked up by the ear and then conducted through the ear canal to the eardrum." Naruto, ep. 06, 3 min 22 s	This speech occurs in a fight situation, in which an opponent is knocked out using a device that emits sound.	The cause/effect relationship is explained, using a scheme showing the anatomy of the auditory system to link the sound emitted to the opponent's imbalance. In this example, the causal relationship is accompanied by a visual representation.

Source: Research data

Table 3: Characteristics of the subcategories created for fictional or fantasy representations

Categories	Characteristics
Terms/expressions with scientific referent and dissimilar/fictitious meaning	Terminologies that find references in science, but whose meaning is of a fictitious or fantasy nature, differing from the scientifically accepted concept.
Example	"If you want to become a Pokémon Master, you must evolve Pokémon once you catch them." Pokémon, ep. 14, 6 min 55 s Evolution is reported as a rapid change in the shapes and powers of Pokémons, as opposed to the gradual and slow process that leads to genetic changes.
Fictional or fanciful terms and explanations with approximations to scientific ideas	Fictional idea presented with rhetorical characteristics or support of ideas with meanings close to scientifically accepted ones.
Example	"An advanced blood heritage from a clan. It's jutsu, a skill passed down from generation to generation, within the same family. Due to their unique abilities, these families became mercenaries." Naruto, ep. 17, 9 min 20 s While this explanation was taking place, a moving image of a DNA molecule was displayed to illustrate parental heritage.

Source: Research data

Table 4: Representations of scientific content in anime divided between the constructed

Anime	Scientifically accurate representations		Representations with fictional or fantasy content	
	Mentions	Explanations	With scientific referent and dissimilar/fictitious meaning	Fiction/fantasy with approximations to scientific ideas
Pokémon	21	20	1	4
Dragon Ball Z	14	7	0	3
Naruto	19	10	0	4
Full Metal Alchemist	35	9	1	6
Dr. Stone	97	68	0	0
Cells at Work	40	37	0	0
Total	226	151	2	17

Source: Research data

(1979) did not focus on anime or other objects of media culture, one can infer the potential intercollective exchange when science representations are inserted into a product of media culture, acting as a mediator for the public sphere. As a media

products, anime is designed with other interests in mind but can influence the public understanding of science more than formal education itself, since it is usually more eye-catching and reaches a greater public (Van Riper, 2003).

Science, or its representation, is a relevant part of the constitution of fantasy worlds in popular media. Kirby (2003, 2008) argues that science in TV series or films provides a perceptually realistic framework that merges accurate and inaccurate science and can serve as a promotional device for some research fields. The significant presence of representations of science strengthens the potential of anime to dialogue with different audiences. To this end, the examination of these representations of science-related content is an aspect to be considered.

Representation of Scientific Content with Accuracy

The scientific conceptual content was present at different levels of depth, from citations of terms to explanations about phenomena, processes, structures and functions. In the category of mentions, a term, expression, comment, or doubt emerges in the midst of scenes, in an exclusively verbal way and without any deepening or emphasis as the narrative continues (Table 5).

In general, the scientific terms showed a correlation with science. The sections on “compression force to maintain entropy” or “heavy water” are understood to have the same scientific meaning, thus enabling a viewer with this understanding to create a more comprehensive view of the scene based on science. In this sense, they can prompt

individuals to seek such understanding or allow such situations to be brought into the scope of formal education.

Scientifically accurate content representations were also classified as explanations. In this category, greater emphasis was placed on scientific content because it was more obvious or because of its more explicit connection with the scene. Dr. Stone and Cells at Work once again stood out quantitatively, but Pokémon also demonstrated a significant amount of scientifically accurate content. The excerpts exemplify how the representation of the content and the plot in the scene are interwoven (Table 6).

The difficulties the character Goku (in the scene in question in Dragon Ball Z) faces in staying upright and moving around literally represent a hypothesis of what would happen if a human being could be on a planet with higher gravity. Thus, plot and scientific content become interdependent in these scenes. Spectators who had never thought about the situation or who would be unable to connect it to the scientific principle involved may gain an understanding about the effect of the action of a higher gravitational force. Communication about the concept or process within the context of the anime also occurs between the anime and its viewer, conveying scientific ideas.

In addition to the use of verbal text, a significant portion of the records demonstrated the combination of visual resources,

Table 5: Examples of mentions, type of content representation in all the anime investigated

Term/definition/scientific process addressed	Citation excerpt	Description
Electrical insulation	“Rubber gloves will come in handy. Rubber isolates electricity.” (Pokémon, ep. 1, 9 min 39 s)	Pikachu is angry and sends electric shocks at Ash. Then Professor Carvalho talks about rubber gloves, so that Ash uses them to protect himself against shocks.
Food storage temperature	“Kohaku: - I know that frozen things don’t spoil. Senku: - That’s right, we can end up with a better way to preserve food. (Dr. Stone, ep. 11, 14 min 21 s).	The characters try to build a refrigeration machine when one of them mentions its role in preserving food.
Rarefied air/gravity	“It’s very hot here, the air is rarified and the gravity here is much greater.” (Dragon Ball Z, ep. 147, 17 min 30 s).	Upon entering a room that gives access to an inhospitable environment, Trunks makes the comment.
Density	“This water isn’t normal. It’s dense, heavy. (Naruto, ep. 08, 6 min 25 s)	During a fight, one of the characters is thrown into the water and, upon feeling the water, makes the comment.
Liquefaction, vaporization, compression, entropy	“It liquefied the air around it, reduced the volume and vaporized everything at once, producing a shock wave. The light that came from the intense heat that was created by compression force to maintain entropy.” (Full Metal Alchemist, ep. 09, 11 min 43 s)	During dinner, when an alchemist talked about the manipulation of energy (which occurred at the beginning of the episode), he explained it.
Hemoglobin	“Red blood cells: They are red because they contain large amounts of hemoglobin. They carry oxygen and carbon dioxide through the bloodstream.” (Cells at Work, ep. 01, 02 min 00 s)	The character Red Blood Cell (people analogous to cells) arrives at the scene; she is given emphasis, and the function of red blood cells is described).

Source: Research data

Table 6: Examples of excerpts classified as explanations that used verbal communication

Citation excerpt	Identified concept	Anime
“That’s why it’s difficult to move even though it’s small. This planet has a very strong gravity force; I think it’s 10 times greater than your planet. That means your weight increases 10 times more than normal.”	Weight force	Dragon Ball Z, ep. 19, 7 min 24 s
It was gasoline. I refined it from PET bottle caps. Think about the molecular structure of polyethylene, idiot. Simply cut the hydrocarbon molecules into the same length as the gasoline molecules. [...]	Organic chemical reaction	Dr. Stone, ep. 1, 0 min 18 s
“Red blood cells: They are red due to the high amount of hemoglobin. They carry oxygen and carbon dioxide through the bloodstream.”	Function of blood cells	Cells at Work, ep. 01, 2 min 00 s

Source: Research data

making the content communication process more evident. The representations that combined textual and visual modes direct one's attention toward the plot with a certain intentionality and greater intensity. In total, 108 situations were identified. Table 7 exemplifies several cases.

Through verbal, imagery, and sound language, the anime's plot provides entertainment and joy, while simultaneously favoring the communication of scientific ideas. The sometimes intentional combination of these varied resources is a way of reiterating and legitimizing scientific content, providing a didactic rhetoric that clearly illustrates the connections with the anime universe, and enabling the process of public communication about science to be expressed with greater emphasis. The use of these various linguistic resources can fit into what Fleck (1979) called a vivid picture, in which the inclusion of illustrative and apodictic elements modifies the language with the aim of making it esthetically pleasing for a broad audience. There is an inherent simplification of controversies and historical facts that generate simplified knowledge, in addition to the use of general representations, analogies, and metaphors.

Characteristic of the popular presentation is the omission both of detail and especially of controversial opinions; this produces an artificial simplification. Here is an artistically attractive, lively, and readable exposition with, last but not least, the apodictic valuation simply to accept or reject a certain point of view. Simplified, lucid, and apodictic science—these are the most important characteristics of exoteric knowledge. In place of the specific constraint of thought by any proof, which can be found only with great effort, a vivid picture is created through simplification and valuation (Fleck, 1979, p. 112–113).

Japanese animation can precisely contribute to expand the communication about scientific ideas by allowing fans to converse with science or understand it if they are interested, which would favor the shifting of ideas. The exchange of such ideas among groups unfamiliar with science can thus provide new outlooks, facilitating changes in thought styles. Therefore, one can ponder about the intercollective communication of ideas, once anime spreads scientifically accurate representations among different types of fans, both conversant with and uninformed about science, giving rise to debates in informal environments (James, 2020). According to Fleck:

Popular exoteric knowledge stems from specialized esoteric knowledge. Due to simplification, vividness, and absolute certainty, it appears secure, more rounded, and more firmly joined together. It shapes specific public opinion as well as the *Weltanschauung* and, in this form, reacts in turn upon the expert (Fleck, 1979, p. 113).

The concern with this communication process is more evident in some anime, such as *Cells at Work*, in which there was intense participation of experts as consultants for the dissemination of scientific knowledge (Cintya et al., 2021). Anime is a contemporary media objects, situated in a universe in which such productions diversify and serve a broad spectrum of contemporary audiences. Several works, not necessarily recent, have demonstrated the potential for critical discussions of science based on cultural productions, including comic books (Carter, 1988; Tatalovic, 2009; Spiegel et al., 2013), manga (Jaouen and Robin, 2022), and also anime (Ryu et al., 2020; Mahler and Mayer, 2024). Carter (1988), for example, highlighted the validity of different principles, equations, and chemical processes in comics as diverse as Donald Duck, X-Men, and the 1977 Marvel Comic adaptation of Peter Benchley's "The Deep," among others. The author suggests that the analysis of these processes in media could improve understanding of science. Peiro Agustín et al. (2021) proposed the identification of vertebrates in Pokémon to distinguish and associate the fictional creatures with the organisms of vertebrates. Mahler and Mayer (2024) state that in addition to the validity of scientific principles, esthetic elements influence motivational and attentional aspects.

It should be noted, however, that the presence of factual and accurate representations of science in popular media does not ensure a correct understanding of scientific aspects. A variety of factors influence the ideas generated by audiences upon viewing popular media, such as their relationships with science, personal and religious beliefs, political leanings, historical discourses, experiences watching other similar media, cultural and social aspects, etc. (Myers and Abd-El-Khalick, 2016; Orthia et al., 2012; Rose, 2003). Studies focused on science interpretation of popular media by different audiences have found that even the representation of conceptually accurate content can naturalize the relationship between realism and fantasy or even produce a sense realism when they portray

Table 7: Explanations of scientific concepts in anime, using multimodality

Verbal text	Visual representation (description)	Anime
It was smart. Rhydon's horn acted like a lightning rod. Misty: "I think Rhydon was shocked by that."	The image depicts a bolt of lightning striking Pokémon's horn, causing the dissipation of electricity into the ground (like a lightning rod).	Pokémon, ep. 60, 18 min 00 s
[...] The vibrations of molecules in the air create a sound wave. These vibrations are picked up by the ear and then conducted through the ear canal to the eardrum. The rest, as they say, is anatomy. [...]	The anatomy of the inner part of the ear is represented in details. Each part is shown together with the verbal text that explains how sound is conducted through it.	Naruto, ep. 06, 3 min 22 s
Inside the human body, around 37.1 trillion cells are working full of energy. [...]	A sketch of the human body is represented, showing the blood circulatory system (blood vessels) in red.	Cells at Work, ep. 1, 00 min 00 s.

Source: Research data

non-realism (Barnett et al., 2006; Myers and Abd-El-Khalick, 2016; Szu et al., 2017).

Another point to keep in mind is that a large portion of audiences is not necessarily interested in a profound analysis of scientific features. At the same time, the search for parallels and connections with real science, whether or not their presence is intentional, is a form of appreciation that can encourage debate and broaden points of view. As Locke (2005) argues in the case of superhero comics, an idea that can be extended to anime, these products can constitute a cultural arena whose debate on the meanings of science can encompass both specialists and non-specialists, expanding the process of communicating scientific ideas.

Representation of Scientific Ideas with Fictional or Fanciful Characteristics

Science fiction or fantasy, even for the purpose of entertainment, uses language with scientific references, adding to them elements that include magic, fantasy, and mysticism to build the plot. That is the case of anime. Most of the characters are non-human or fantastic in nature, and even humans are endowed with superhuman powers, are resurrected, endure extreme physical conditions, and display traits that are not consistent with human nature. These traits imbricate with scientific themes. Hence, it is worth pointing out the aspects of fantasy portrayed in all anime.

Two types of mobilization of fantasy or fictional representations were identified: Terms existing in the literature, but with dissimilar explanations; and fictitious or fanciful terms and explanations that are close to scientific ideas. The first type of mobilization was identified only in Pokémon, but appeared persistently. The term “evolution,” for example, was identified in 30 scenes, contained in 18 episodes. In the anime, the idea of evolution is presented as a transformation that occurs in the “living being,” which enables it to attain another stage of enhancement of physical capabilities instantly. Evolution in Pokémon differs from the scientifically accepted notion, i.e., a gradual process, depending on environmental conditions and variability of living beings, which leads to dynamics of genetic changes in living beings over time, an idea to which even students and teachers are resistant (Oliveira et al., 2022; Penaloza et al., 2021).

In the case of fictitious or fantasy terms and explanations that revealed the use of scientific ideas or rhetoric to support

them, 18 cases were identified. One of the most emblematic examples is the Chakra, located in the anime Naruto (Table 8). The explanation uses scientific rhetoric, including a coherent representation of the human cardiovascular system in comparison to the Chakra energy system. The use of argumentative rhetoric similar to that used in science is what gives this representation scientific contours. Such content representations are established as analogies and are characterized by both similarities and simplifications of scientific ideas.

Analogies are strongly present in the anime Cells at Work, in which human characteristics are attributed to the different components of cells. Red and white blood cells, platelets, etc. are represented by human beings, while buildings are parts of the body and streets and avenues are blood vessels. Metaphorical and analogical representations, whose pros and cons for the construction of scientific understanding have been debated for years in science education research (Duit, 1991; Niebert et al., 2012), can give this fantasy nature of anime scientific limitations or inconsistencies. Several studies discuss limited or distorted representations of science in films and books, proposing the idea of using these materials to debate inconsistencies and teach correct science (e.g., Dubeck et al., 1994; Barnett et al., 2006; Smith, 2009). Audiences can absorb information even when they recognize inaccuracies (Barnett et al., 2006). In this regard, the authors endorsed the idea of greater accuracy in representations of science in popular media as a pathway to increase the dialogue between science and fiction.

Contrary to this perspective, there is no consensus between the scientific community and researchers into public communication of science about the potential importance of science content (Szu et al., 2017). On one hand, there is the argument in defense of accuracy to prevent misconceptions; on the other hand, placing emphasis on content could disregard social and contextual aspects. More than pointing out inaccuracies and oversights, however, connections and parallels (intended or not) with real science are a way to appreciate these cultural products, engaging the public and thereby helping them to understand these products (Rose, 2003). The representational science in anime, as multiple and metaphorical, cannot be seen as simplistic or non-science. Locke (2005) pointed out that popular media is a complex portrait of fictional science or non-science. Van Riper (2003) argues that the acceptance of science in popular culture as

Table 8: Explanations of fantasy ideas about chakra and chakra network, in Naruto

Text excerpt	Visual representation
Rock Lee – It is a complex system of circulatory channels that distributes chakra throughout the body. Similar to people’s vascular system, the veins and arteries that carry blood. Ep. 20, 19 min 10 s	A human body is shown schematically. Within this representation, a circle in place of the heart and several lines running through the body emphasize the idea of a vascular system.
Chakra is the elemental energy of life that a ninja uses in jutsu. It is the source of all his power. This energy has two forms: Physical energy, which is present in all the cells of the body that work together, and the spiritual energy, the primary source of the power, which is increased from both power and experience (...). Ep. 10, 11 min 15 s	Representation of the human body showing arrows that portray the presumable energy flow.
Source: Research data	

entertainment and its use in dialogue with the public would be advantageous. Nonetheless, this is not a simple goal to achieve, and the points in which narrative dramatic license are taken require some consideration of the historical and cultural context of the audience, and the context in which the fiction was created.

Problematizing representations can be a way to put scientific themes on the agenda taken from the anime/otaku universe, allowing inferences, considerations, and debates about such themes. They can be seen as vivid, simplified, and organized representations, serving as resources aimed at reaching a varied audience. Again, a parallel can be drawn with Fleck's conception of the presentation characteristics of popular science and emotional plasticity. In particular, its ultimate objective, *Weltanschauung*, a structure that derives from the emotional selection of popular knowledge that is influenced by various fields (Fleck, 1979). For the philosopher, this structure helps to shape public opinion, which allows us to infer that anime could also fill this role. In this approach to Fleck's (1979) thinking, diverse communities (otaku, school, scientific, popular) can provide and receive contributions when talking about and with anime, resignifying understandings, including those of a scientific nature and of the cultural object.

FINAL REMARKS

This work examined six anime of worldwide popularity to find the answer to the following question: Which representations of science are portrayed through anime? Despite the fact that these products are not aimed at the public communication of science, the overall results indicate the strong presence, both unintentional and intentional, of representations of a scientific nature in the plots. The most common were the mentions, which indicate that representations of science in anime tend to be more factual than contextual. In turn, many cases of explanatory nature are strengthened by a combination of textual and visual resources. The inclusion of illustrative and apodictic elements, including visual representations, sounds, and analogies, modifies the language to create an esthetically pleasing effect or a vivid picture, as Fleck (1979) points out. These are characteristics of popular science in media can have a positive effect on the public in terms of accepting science, influencing motivational and attentional aspects, as has been pointed out in several studies (Ryu et al., 2020; Mahler and Mayer, 2024).

However, it is not scientific accuracy simply that would enable the public to understand science. Anime brings to light representations of science that can be seen as metaphorical and not as science itself, but that have strong similarities that allow a public debate about science based on such representations. This complex representation can attract a diverse audience of science experts and non-experts across the world. The search for parallels and connections permeated by scientific meanings can favor an arena of debate and broaden points of view (Rose, 2003; Locke, 2005), thus promoting the exchange of ideas needed for intercollective communication. James' work (2020)

demonstrated that fans, both experts and amateurs in the field of science, engage in science-related discussions in non-school spaces, such as conventions. These spaces are favorable for the exchange of ideas linked to science, typical of Fleck's (1979) intercollective communication.

In the classroom, the potential of anime for discussing science has also been highlighted (Mahler and Mayer, 2024). The tension between plausibility and accuracy can be a pathway to engage the audience in science discussion. Problems such as: "Would be possible to live in a place with two or three times the Earth's gravitational force?" "What would be the effects on the body?" are examples of situations that may be examined and investigated by students.

It can therefore be assumed that there is a potential role for anime in this exchange and the furtherance of intra- and intercollective interaction of scientific ideas, for their discussion can involve specialized, school, and popular audiences. However, these are conjectures based on a study of anime content and modes of communication. They are therefore limited, emphasizing representations of scientific content. Furthermore, the impact of anime on audiences cannot be fully understood by investigating solely the representations of science. Cultural contexts of the public interfere decisively in ideas generated by viewing popular media, sometimes in contradictory ways (Orthia et al., 2012). Further studies can advance from conjectures to empirical evidence, especially if they are addressed in debates that can be fomented among the most faithful admirers of anime. Besides, science as a process and its impact on society was absent from the analysis, as was the role of scientists. The analysis did not include a debate addressing the moral and social consequences of science and technology, which is a possibility in popular media. Ultimately, it is hoped that this study will also encourage an intracollective debate, encouraging other researchers to explore the universe of anime and to scrutinize these productions to disseminate and discuss science. As Fleck (1979) explains, popular science feeds most people's knowledge, and can be retroactive to the specialist, closing the intercollective cycle.

ETHICS STATEMENT

This study did not need ethics approval because it is a video-analysis-based study.

DISCLOSURE STATEMENT

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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