Aesthetic Values in Science

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Abstract

Scientists often refer to their experiments, theories, images and instruments as beautiful and report that their scientific work is a source of aesthetic experiences. How do such aesthetic values affect scientific activities, and can aesthetic values play a cognitive role in science? In this chapter, I identify the different levels at which aesthetic values shape scientific products and processes, reflect on how philosophers have justified the cognitive role of such aesthetic values, and draw insights from recent discussions on the aesthetics of scientific practice for the values in science debate.

1. Introduction

In recent years practitioners from different fields have begun to shed light on the commonalities between art and science and the role played by beauty within their fields. The aesthetics of science has become a fast-growing subfield in philosophy of science, generating important collaborations between philosophers, sociologists, historians, artists, scientists and science communicators. Original contributions in this literature connecting art and science focused on the notion of representation (Frigg and Hunter's 2010, Bueno et. al. (2018)). Broadening the scope further, Ivanova and French's (2020) collection offers new directions in the debate, such as how beauty affects the evaluation of scientific theories, the relationship between beauty and

the acquisition of understanding though models, images and thought experiments, and aesthetic experiences going beyond beauty into explorations of the sublime in science. Ivanova and Murphy (2023) further develop novel perspectives on the debate by investigating previously understudied questions in philosophy of science, such as how aesthetic values shape the design, performance and results of experiments, whether there is stability in how the experiment is appreciated aesthetically, what commonalities can be found between artistic and experimental practices, and what function negative aesthetic values may play in modern highly collaborative and AI driven experiments.

Several books and articles have also explored important connections between aesthetics and science. McAllister (1996) asks whether practitioners in different scientific traditions agree upon a set of aesthetic values, and whether variability of such values may undermine their rational use in science. One of the main ongoing questions in the field is whether beauty can play a positive role in the achievement of epistemic goals such as truth or understanding. While some scholars have argued that aesthetic values can be relevant epistemic factors, as conditions of understanding (Breitenbach (2013), Elgin (2020), Ivanova (2021, 2022), Turner (2019), others have expressed concerns beauty in science can operate as a cognitive bias stalling scientific progress (Hossenfelder (2018)). Examination on aesthetic dimensions of scientific practices have also emerged, giving rise to what I will call 'practice-based aesthetics of science'. Wylie (2021) and Turner (2019) pay close attention to the preparation of fossils to understand how aesthetic values shape the preparatory processes and the reception of the final product. The experiment has also received attention in this literature with new questions emerging. Whether experiments can be aesthetically appreciated has recently been addressed both from a philosophical perspective by Ivanova (2021, 2022, 2023a, 2023b) and Parsons and Reuger (2000)) as well as historical perspective (Ball (2023) and Wragge-Moorley (2020)). In sociology, studies on wellbeing in science are showing an interesting link between scientists'

aesthetic experiences in daily practice and their overall sense of purpose, accomplishment and wellbeing (Jacobi C. et. al. (2022, 2023) and Vaidyanathan, B. et. al. (2023)). These works shed new light on the classic questions regarding the goal of science and the role of aesthetic values in it but have also opened a plethora of new directions for exploration particularly when it comes to different scientific practices and experiences scientists encounter in their work.

In this chapter, I reflect on the recent developments in the aesthetics of science literature, identify emerging directions and draw important analogies with the broader literature on values in science. In section 2, I show the breath of contexts in which we can see aesthetic values operating in science and their role in scientific reasoning. In section 3, I present an overview of arguments defending the cognitive role of aesthetic values and the counterargument taking these values to operate as cognitive biases. Section 4 presents what I call the 'practice turn' in the aesthetics of science, where I show novel developments in the literature asking questions about the role of aesthetics in the daily work of scientists. In section 5, I offer my reflections on the new directions emerging in this field and the future of beauty in science. Section 6 is the conclusion.

2. Aesthetic values in science: where do we find them and what do they do?

We can distinguish between three different levels in which aesthetic judgements are made in science: the objects of scientific inquiry, the products created by scientists, and the processes by which these products are made (Ivanova (2017a, 2020)). Starting with natural phenomena, entities and processes, the objects of scientific enquiry can exhibit aesthetic properties and evoke aesthetic experiences. From rosy bonnet mushrooms, rainbow lorikeets and hexagonal honeycombs, to sunsets and waterfalls, nature is a source of aesthetic experiences (Brady and Prior (2020), Parsons (2023)). Aesthetic experiences are also afforded when engaging with

nature under carefully crafted experimental settings, such as the observation of crystallisation under a powerful microscope or the decomposition of light through a prism.

The products scientists create in their work are also subject to aesthetic appreciation. Scientific theories, experiments, images, models, instruments (Ivanova (2017, 2024), Ivanova and French (2020), Ivanova and Murphy (2023), McAllister (1996)) as well as mathematical proofs (Dutilh Novaes (2019), Kuipers (2002), Montano (2002)) are often praised for their beauty, elegance, symmetry, simplicity, unity. For instance, Newtonian mechanics can be seen as a highly beautiful theory due to its elegance in describing the motion of bodies with three rather simple laws of motion and a law of gravitation featuring few parameters. Einstein's theories of special and general relativity are regarded as beautiful due to their unifying explanatory power achieved through a small set of scientific principles (Chandrasekher (1987), Ivanova (2020)). Galileo Galilei's thought experiment on falling bodies is among the most beautiful thought experiments. As Murphy (2020) argues, this experiment utilises economic concepts and materials to demonstrate an important novel concept: that of acceleration. Scientific images also have aesthetic value. Take the images NASA publicly disseminated in 2021, produced with the James Webb Space Telescope, focus of much discussion due to their beauty. To produce the images, scientists used aesthetic values when translating the data collected by the telescope when, for instance, selecting colours not detected by the telescope to present the data (Ivanova 2022).

In addition to the objects of study and products of scientific activity, the very process of developing a theory, deriving a mathematical proof, designing and performing a scientific experiment or preparing a scientific image, involves the creativity, imagination and aesthetic sensibility of scientists. We can draw parallels between these scientific practices and artistic productions, seeing them as involving creative agency, aesthetic values as well as other goals of the scientist (Anscomb (2023)). In fact, such a connection can be found in scientific work

today just as much as in earlier traditions. Going back to the production of NASA's images, where astronomers made choices in the selection of colours when translating the raw data collected by the telescope into images accessible to the human eye, we can similarly see aesthetic values in the preparation of images in other scientific traditions. For instance, Leonardo da Vinci in anatomy and Robert Hooke in entomology, would enhance the aesthetic features of their subject matter in their depictions, generating in the viewer awe and wonder when engaging with the depicted specimen. Today scientists often use aesthetic values when performing and designing experiments and images. Aesthetic judgements are integral to many scientific fields, from astronomy to biology, and medicine to chemistry and palaeontology. The very process of scientific discovery is also often compared to artistic production. The French physicist, historian and philosopher of science, Pierre Duhem, argues that it is impossible to follow the process of constructing a physical theory "without feeling keenly that such a creation of the human mind is truly a work of art" (1954, 24). Ernest Rutherford similarly claims that "the process of scientific discovery may be regarded as a form of art," continuing that "a well constructed theory is in some respects undoubtedly an artistic production" (quoted in McAllister 1996, 14). In addition to seeing the creative process in science as parallel to artistic creativity, Henri Poincaré explicitly devises an account of scientific creativity at the heart of which is the aesthetic sensibility of the scientist, which acts as 'the delicate sieve' that scans and evaluates which ideas that the mind produces are useful by judging first their aesthetic appeal. At the heart of this account is the idea that "care for the beautiful is care for the useful", that the elegant, coherent and beautiful hypotheses, experiments or proofs are likely to prove more fruitful to the scientists in their inquiry than the less coherent, disjointed or overcomplex ones. (Ivanova 2017b).

So far I have illustrated the rich aesthetic dimension of science, but what is the function of these judgements? While aesthetic values are often seen as a motivator in scientific inquiry,

some believe aesthetic values are epistemically significant, in facilitating understanding or indicating truth. To illustrate the motivational role of aesthetic values, the French mathematician Henri Poincaré argues that "[t]he scientist does not study nature because it is useful to do so. He studies it because he takes pleasure in it, and he takes pleasure in it because it is beautiful" (2001, 368). Poincaré's view on the role of aesthetic values in science, however, goes beyond seeing these values purely as motivational. Rather, aesthetic values are constitutive of our achievement of understanding: "I am not speaking, of course, of the beauty which strikes the senses, of the beauty of qualities and appearances. I am far from despising this, but it has nothing to do with science. What I mean is that more intimate beauty which comes from the harmonious order of its parts, and which pure intelligence can grasp." (ibid.) The Nobel laureate Subrahmanyan Chandrasekhar's book *Beauty and Truth* further offers a series of arguments to convince that beauty guides physicists to the truth, claiming that "in the arts as in the sciences, the quest is for the very same elusive quality: beauty." (1987, 52) During the early days of Einstein's general theory of relativity, many expressed the belief that the theory's beauty offered support for its truth. For instance, Paul Dirac claimed that "one has a great confidence in [a] theory arising from its great beauty, quite independently of its detailed successes." (1980, 40) Before Arthur Eddington's expeditions in 1919 that offered empirical support for the theory, Dirac argued that "[o]ne has an overpowering belief that [the theory's] foundations must be correct quite independently of its agreement with observation." (ibid.) This conviction was shared by many physicists at the time, including Eddington himself as well as Werner Heisenberg, who claimed that "[i]f nature leads us to mathematical forms of great simplicity and beauty we cannot help thinking that they are "true," that they reveal a genuine feature of nature" (1971, 68). In the following section, I focus on arguments defending, and arguing against, the epistemic significance of aesthetic values.

3. Beauty: a guide to the truth or systemic bias?

One of the important issues in the literature on science and values has been the question of how, if at all, to distinguish epistemic or cognitive values from non-epistemic or contextual values (see e.g., Douglas 2013; Longino 1996; Rooney 2017; Steel 2010). In the context of aesthetic values, some have explored whether aesthetic values are epistemic. How can we justify the idea that beauty leads to the truth? One way is to argue that there is evidence from past practices that being guided by aesthetic value leads to empirical success or approximate truth. Chandrasekhar argues that "we have evidence that a theory developed by a scientist, with an exceptionally well-developed aesthetic sensibility, can turn out to be true even if, at the time of its formulation, it appeared not to be so" (1987, 64). Chandrasekhar argues that uncovering the beauty of nature is a primary motivation in science and a guide to the truth. Focusing on the beauty of Einstein's theory of general relativity, to be found in the unification of the fundamental concepts of space and time, matter and motion with elegance and beauty, he claims that such values are to be trusted because they have led us to the truth many times before. Another track record argument can be found in James McAllister's *Beauty and Revolution in Science*. Rather than defending the idea that beauty leads to the truth, McAllister focuses on empirical adequacy of scientific theories and argues that aesthetic values can be good predictors of such success. McAllister argues that scientists form aesthetic canons, a set of aesthetic values reflected in successful theories adopted at the time and their predecessors. When a new theory comes along, even if the theory has yet to receive confirmation, scientists can rationally make an aesthetic induction from the past and infer whether a new theory is to be trusted on the basis of its aesthetic features, given that those are constitutive of the adopted aesthetic canon. For McAllister, however, aesthetic cultures and canons are unstable. The history of science is a history of the evolution of the concept of beauty, with new empirically successful theories revising and transforming the aesthetic canon communities adopt.

Ullian Montano (2008) challenges the prescriptive accuracy of this framework, pointing to cases where epistemically successful theories or mathematical proofs are adopted by communities but are met with resistance because they do not satisfy the scientists' aesthetic sensibilities. McAllister's theory predicts that with time scientists learn to appreciate the traits of successful theories and revise their aesthetic canon. Montano argues that this is not the case, pointing to the case of computer assisted proofs in mathematics where despite their success, such proofs continue to be considered ugly. Ivanova (2020) further points to the case of quantum mechanics and the standard model which despite being highly successful have not resulted in the community revising their aesthetic canons and continue to be regarded as displeasing.

Another issue with track record-based justifications are cases of aesthetically pleasing theories that have turned out to be false. Projects in high-level physics, such as the Kaluza-Klein theory, provide a beautiful way of unifying gravity and the other gauge fields, but are false. In *Lost in Math: How Beauty Leads Physics Astray* Hossenfelder (2018) reflects on such cases arguing that beauty can operate as a systematic bias in a community, leading to unproductive projects and stagnation of ideas. On the other hand, as noted earlier, we also see that successful theories can violate our aesthetic expectations – as is the case of the standard model and quantum mechanics. Ivanova (2020, 2024) argues that such inductive arguments are ultimately not going to convince when it comes to the epistemic role of aesthetic values, since inductive arguments pulling in both directions can be made. Thus the recent move of identifying the cognitive role of aesthetic values not as truth tracking but as conditions for understanding.

Motivated by the move in philosophy of science to study how models represent the world via omission and additions of features not present in the target system, Catherine Elgin (2007), among others, argues for a non-factual account of understanding. The goal of science is not to deliver true propositions but to allow us to understand how to manipulate and interact with

systems we are interested in. The move towards non-factual understanding presents a shift in the debate on the goals of science, and proponents have offered their reflections on the role of aesthetic factors in achieving this epistemic goal. Elgin (2020) argues that aesthetic values are constitutive part of our desire to gain understanding of the world and operate as 'gatekeepers; leading us to productive ideas. This is not to say that these are non-revisable and fixed no matter what; these values can come in friction with other values we hold, but their role in the acquisition of understanding is central. Ivanova (2017, 2020) further argues that aesthetic values are conditions of human understanding, reflecting Poincaré's insightful account according to which "[i]n formulating a general, simple, and formal law, based on a comparatively small number of not altogether consistent experiments, we have only obeyed a necessity from which the human mind cannot free itself" (Poincaré 2001: 100). This aesthetic experience, the 'harmony' we experience when we reflect on our theories "is at once a satisfaction of our aesthetic requirements, and an assistance to the mind which it supports and guides." (ibid.:396-397) Similar insights come also from Kantian scholarship where aesthetic values are seen as conditions of understanding (Breitenbach (2013)). Empirical studies also seem to support the idea that aesthetic values constitute human reasoning and understanding, with Tania Lombrozo arguing that "when children and adults generate and evaluate explanations, they recruit explanatory virtues, such as simplicity and breadth, as evaluative constraints on reasoning. As a result, they are more likely to generate and favor broad and simple hypotheses, and to discover broad and simple patterns" (2016, 749). Our desire for simplicity, unity, elegance then affects both our preferences for what hypotheses we construct and what patterns in nature we focus on. This is not to say that if systematically in error, people resist revising such aesthetic preferences, but that there is a barrier to accepting complex and messy explanations. So far, we reflected on the justification of aesthetic values when it comes to epistemic goals, such as truth, empirical adequacy, understanding. However, in the very

recent literature, we are seeing attention being paid to daily practices of scientists and a desire to understand how aesthetic values shape these activities. The next section explores this recent shift.

4. The turn to scientific practice

In (1989) *The Neglect of Experiment*, Allan Franklin points to the important epistemological questions arising in experimental practice that had been left out of philosophy of science due to the narrow focus on theory over practice, leaving the autonomous life of experiments understudied. I voice similar concerns with the aesthetics of science literature where much attention has been paid on the role of aesthetic values in the evaluation of scientific theories, leaving much of scientific practice understudied. Yet recently we are seeing a move towards what I will call 'practice-focused aesthetics of science'. Recent works focus on the aesthetic judgement at play in the preparation of fossils and the speculative reasoning they afford (Turner 2019, Wiley 2021, Currie (2024)), chemical biology, including the beauty of molecules, molecular images and synthesis (Parsons 2012), anatomy (Ambrosio and Clarke 2018), and thought experiments (Murphy 2020). Crucially, we have seen the emergence of a debate dedicated to the aesthetics of scientific experiments (Ball (2024), Parsons and Rueger (2000), Ivanova (2021, 2023a, 2023b, 2024), Ivanova and Murphy (2024) and Ivanova et.al.(2024)).

In 'What is a Beautiful Experiment' (2023) Ivanova offers a new framework to understand the aesthetic value of experiments. Several aesthetic aspects to the experiment are identified: the subject matter, the instruments employed, the design of the experiment, its performance, its results and the process of creating it. While all these aspects can involve the aesthetic sensibility, Ivanova draws a distinction between *perceptual beauty*, the visual or tactile beauty of a 18th century microscope, for instance, and *intellectual beauty*, experienced when we appreciate how the design of an experiment connects to its significance. A beautiful

experiment, according to Ivanova (2023, 2024), is one that has an optimal design and produces significant results, where the latter are understood in a pluralistic way – they can align with expectation by confirming or discovering something theoretically expected, or by producing disruptive results that spark new investigations.

Attention is also being paid to the diversity of aesthetic experiences in science themselves. Arcangeli and Dokic (2020), for instance, offer an illuminating categorisation of aesthetic experiences in science, arguing that what we consider 'positive' aesthetic experiences, usually associated with pleasure, beauty, proportion, elegance, symmetry, are due to fluency processing, ease of understanding the subject matter. Disfluent processing, on the other hand, is associated with more sublime experiences; those by their nature have both a positive and negative component. Sublime experiences point to our limitations, smallness and can be experienced as disruptive and negative. They are, however, cognitively significant, since they can illuminate the limitations of our theoretical frameworks and thus help us expand them. Murphy (2024) further focuses on the value of profundity. Focusing on thought experiments such Schrodinger's cat, Murphy argues that thought experiments can be aesthetically valuable because of their ability to convey important ideas with minimal materials. Murphy demonstrates the scope to broaden the class of aesthetic values that are studied in science and highlights a potential limitation in the fluency processing account of the aesthetic experience in science. While fluency can help us explain the presumed connections between the aesthetic and the epistemic, profundity can align more with the disfluency account, opening space for a more pluralistic account of aesthetic experiences in science and their cognitive dimension.

Moving towards negative aesthetic values, Sophie Ritson (2024) studies ugly experimental results. In high energy physics, where physics are working on theories beyond the standard model, Ritson argues that scientist are explicitly looking for ugly, non-conforming, results because they believe such surprising and unexplainable results can push them in directions.

Similarly, Stuart (2024) explores experiments designed using Artificial Intelligence and argues that these hold great epistemic value by not conforming to our aesthetic values. Seeing aesthetic values as limiting the set of possibilities human scientists can consider, Stuart argues that AI designed ugly experiments can generate epistemic goods. In the latter works we see the epistemic and aesthetic connection receiving new analysis where negative aesthetic values are seen as epistemically significant too.

5. New directions in the aesthetics of science

One promising direction emerging in the literature concerns the connections between art and science and aesthetics and philosophy of science. While these analogies took central stage a couple of decades ago when it comes to the development of the literature on scientific models and representation, currently philosophers of science are turning to broader explorations and analogies. For one, attention is paid to the diverse aesthetic experiences and values in science, from sublime (Arcangeli and Dokic (2020)), and profundity (Murphy (2023), to negative aesthetic values such as ugliness (Ritson (2023), Stuart (2023)). In addition to this, the idea of aesthetic cultures is receiving new attention. McAllister's work explores aesthetic cultures and revolutions by focusing on theorising. Parsons and Reuger (2000) argue that aesthetic appreciation of experiments changes when methodological changes in science occur, giving the experiment different role and thus placing different focus on its aesthetic value. Ivanova (2023) on the contrary argues that we can see stability in how experiments are aesthetically appreciated, specifically when it comes to appreciating the beauty in a well-designed experiment with significant results. Anscomb (2023) appeals to 'functional beauty' to understand the beauty of experimental art in the 20th century, much of which focuses on the rejection of beauty. Despite the dadaist movement divorcing with the idea of visually pleasing beauty, Anscomb argues that such works can still be functionally beautiful which we appreciate

by reflecting on how an artist has achieved their goal with the materials of choice, rather than the visual features of the artwork. Anscomb makes the case that the concept of functional beauty accommodates the aesthetic value not only of experimental art but also of scientific experiments. Ivanova (2023) further argues that such conception can also be used in contemporary large-scale experiments where there is a sense of distance between performance of the experiment and the observation of a result, appreciating the relationship between the design and the result can unveil its 'intellectual beauty'.

Another important area of emerging research concerns the use of Artificial Intelligence in creative labour and the role of creative agency in scientific work. Stuart (2023) discusses a case from quantum mechanics in which AI assists in finding novel solutions to experimental configurations. As discussed above, being unconstrained by our aesthetic requirements, argues Stuart, AI can offer scientists a broader range of possibilities that will nevertheless be aesthetically displeasing. Ivanova (2024) argues that in specific contexts AI could enhance the creative possibilities of scientists, but there are also concerns that AI will ultimately produce convergent ideas which in the long term could compromise the pursuit of radically novel ideas, often seen as constitutive of scientific progress, (Wadinambiarachchi et.al. (2024)). Ivanova et.al (2023) also reflect on the sense of creative agency for broader scientific goals, such as flourishing and well-being. Their study shows that scientists who feel creatively involved in their work feel a higher sense of aesthetic value and well-being. Murphy et.al. (forthcoming) also offer an illuminating case for the role of creative agency and embodiment in the performance of scientific experiments, calling for further attention to be paid to this aesthetic aspect of experimental work. These aspects posit new and understudied implications for the involvement of AI in scientific work and open further questions for exploration on the relationship between scientific progress, aesthetic values and wellbeing in science.

Beyond the new topics emerging in the literature, we also see a shift towards the use of diverse methodologies and interdisciplinary engagements. The core work in this topic had previously primarily engaged with historical case studies or scientists' own reflections on their work, while the more recent literature shows diversification of methods, with quantitative and qualitative methods being used. These methods illuminate contemporary thinking among scientists today and complement theoretical frameworks arrived at by case studies. One example of such work is Stuart's ethnographic work, looking at the role of creative agency in one lab, closely interviewing four practitioners and studying how their positionality, career stage and gender affect their perception on the role of creativity in their work. Another example is the work of Vaidyanathan, B. at al. (2023), offering large quantitative data on the aesthetic experiences of over 3000 biologists and physicists in four countries and qualitative data from detailed interviews with 215 scientists. Data from this study has supported the theoretical framework on the aesthetic levels of scientific experiments developed by Ivanova (2023), which had been arrived at by examining historical case studies. In their collaborative work, Ivanova et.al. (2023) offer further support for this framework, showing that contemporary scientists identify the aesthetic significance of experiments in the same ways. The quantitative study also shows some interesting places of deviation, opening further questions for exploration, such as the role of agency in contemporary experimental settings. Many philosophers of science have been defending the use of empirical methods as complementary to traditional case studies, including Nersessian (2009), Stuart 2019, 2022, Beebe and Dellsén 2020, Wilkenfeld and Lombrozo 2020, Schindler 2022, Kozlov (2023b), and Stuart (2019, 2022) and Hangel and ChoGlueck (2023). Such methodologically diverse studies are emerging in the aesthetics of science and promise to offer support for existing theoretical frameworks and identify further areas for research.

6. Conclusion

The debate on values in science has traditionally been divided by those who advocate for the "value free ideal," raising awareness that individual values can operate as cognitive biases that harm science, and those who argue that science cannot and should not be value free. Feminist philosophers of science, for one, have pointed to the values a community ought to employ to identify and amend harmful individual biases, such as equality among practitioners and facilitation of democratic discourse (Longino (1990). The debate has been primarily framed around the moral and political values in science, and in this debate aesthetic values are missing. What can we learn from the above discussion about the place and role of aesthetic values of science for this broader discourse? Some worry that beauty might operate as a bias just like gender bias, stifling scientific progress. I think we will be missing something important about scientific practice, however, if we understand aesthetic values in science as harmful biases. What we learn from the aesthetics of science is that there is more to these values and experiences that science affords us. Aesthetic values are held closely by scientists, they can lead to productive ideas and yet sometimes also mislead. We can see from ongoing debates in particle physics that the community is reflecting critically on their aesthetic preferences and considering whether to pursue aesthetically disvalued ideas in the goal of broadening possibilities, which aligns with how the values literature more broadly has been debating the conditions under which particular value influences are productive or unproductive in science (Elliott and Resnik 2023; Holman and Wilholt 2022).

But the aesthetics of science literature also studies why scientists persist in the pursuit of certain hypotheses, their daily practices in the lab or in the field, and whose studies point to the rich aesthetic life that acts as a motivator and guide in the pursuit of understanding of the world. This could be a model for the broader field of science and values to consider the rich variety of ways that values relate to scientific practice. Building on the argument from inductive risk

(Douglas 2009; Elliott and Richards 2017), there has been a tendency for this literature to focus primarily on how values influence hypothesis assessment, but contemporary discussions of aesthetic values illustrate the benefits of considering a wider variety of ways that values can relate to scientific practice. This chapter demonstrates how rich scientists' aesthetic life is by identifying the levels at which aesthetic values are experienced and their connection to other scientific goals that make scientific activities possible.

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