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From the Big Bang to Life beyond Earth: German Preservice Physics Teachers' Conceptions of Astronomy and the Nature of Science

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Abstract: This article reports the findings of a qualitative study that aimed to explore the ideas of 22 preservice physics teachers regarding astronomy concepts both within and beyond the solar system, as well as their understanding of the Nature of Science in the context of astronomy. The study employed a combination of open-ended vignette tasks and ranking tasks, which were adapted from previous research. The results reveal that while the majority of the preservice teachers held appropriate conceptions of astronomy concepts, some of their ideas lacked depth and were superficial. Moreover, their understanding of the Nature of Science in the context of astronomy was found to be limited. This study highlights the importance of providing further education and training in this area, as well as the need to develop and test effective teaching strategies to enhance preservice teachers' and physics education students' understanding of astronomy concepts and the Nature of Science.

Keywords: astronomy; nature of science; empirical investigation; scientific methods

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Citation: Hennig, F.; Lipps, M.; Ubben, M.S.; Bitzenbauer, P. From the Big Bang to Life beyond Earth: German Preservice Physics Teachers' Conceptions of Astronomy and the Nature of Science. *Educ. Sci.* **2023**, *13*, 475. https://doi.org/10.3390/educsci13050475

Academic Editor: James Albright

Received: 7 April 2023
Revised: 4 May 2023
Accepted: 5 May 2023
Published: 6 May 2023

1. Introduction

Astronomy is a subfield of physics in school that sparks great fascination among learners. Space and astronomy are mentioned as topics that generate the greatest student interest among both boys and girls [1]. Perhaps, for this reason, the role of astronomy has recently been strengthened in some German core curricula, such as the 2019 addition of the content area "Stars and Space" to the core curriculum of the federal state of North Rhine-Westphalia, Germany [2], which has not yet implemented astronomy as its own subject like other federal states, such as Mecklenburg-Western Pomerania, Saxony-Anhalt and Thuringia. However, this also means that a lot more future preservice teachers must be prepared for this subject area; they must be able to respond to questions from their students in a professionally adequate manner and also deal with their students' ideas that are still in the process of development [3], not only in astronomy but also regarding upcoming Nature of Science questions. Nonetheless, studies show that despite pedagogical efforts on the part of teachers, inadequate concepts in astronomy are particularly persistent [4]. One reason for this is, for example, that learners have only distorted, limited, or even no direct experience with astronomical objects and quantities [5]. Teachers must then be able to guide the development of concepts, as well as be exposed to questions about the Nature of Science itself (e.g., "How do we know how hot the surface of the sun is?"). Therefore, the aim of this article is to identify adequate and inadequate conceptions among preservice physics teachers in the field of astronomy in Germany and to investigate their handling of questions about the Nature of Science to get an initial idea about where problems in these topics lie and where future research is needed.

2. Research Background

This section provides the theoretical foundation for the empirical evaluation presented later. On the one hand, we provide an overview of the literature on learners' conceptions of astronomical concepts. On the other hand, we spotlight key findings regarding students' conceptions of Nature of Science aspects.

2.1. Learners' Conceptions of Astronomy Concepts

Numerous studies and articles can be found on the conceptions of size among students and (preservice) physics teachers in the context of astronomy [6–8]. For example, 102 Greek students were asked multiple-choice questions about the size of the Earth and the Sun, revealing that 81% of 11- to 13-year-olds knew that the Sun is larger than the Earth [9]. In another study by Summers and Mant [10], 120 primary school teachers from the UK were asked about the size of the Earth compared with that of the Sun. Only 32% of the respondents selected the correct answer from the multiple-choice question, but 87% of them knew that the Earth is smaller than the Sun. Only 2% claimed that the Sun is smaller or the same size as the Earth, while 12% of respondents chose the option "don't know" [10]. Cin [11] interviewed teenage Turks about the size of the Sun, Earth and Moon, and the analysis of the interviews showed that about 43% of the students had a correct idea of the size of the Earth, Sun and Moon. These surveys also show that the studies conducted primarily examined objects in our solar system. Additionally, the surveys were conducted using questionnaires with closed-format items, which sometimes led to heterogeneous results. For example, in Sadler's survey, over 1000 US students were asked two closed-format items about the distance between the Moon and Earth [12]. In the first item, learners had to select the value that corresponded to the distance between the Earth and the Moon from given values. In the second item, learners had to select a model that best represented the distance between the Earth and the Moon. While approximately 30% of learners answered the first question correctly, only about 13% of students answered the second question correctly [12]. General developments of concepts about the solar system were described by [13], who found that teaching with various models improved the level of understanding of 6th grade learners. The key development was found to be the incorporation of the concept of gravity into conceptual understanding. Furthermore, Ref. [14] showed that the degree of agreement with false statements can be significantly influenced by the wording of test items. Ref. [15] also examined the concept of size among students outside our solar system. To avoid the issues with closed-format items, they used the "Norwegian Introductory Astronomy Questionnaire". Unlike other tests, such as the "Lunar Phases Concept Inventory" [16,17], the "Newtonian Gravity Concept Inventory" [18,19], or the "Star Properties Concept Inventory" [20], this questionnaire does not contain closed-format items. Sorting tasks, short-answer tasks, or classroom vignettes are used [5]. In a sorting task, astronomical objects must be arranged in order of their size. In another item, the previously arranged objects must be described. The vignette items also enable the introduction of concrete classroom situations [21]. In their study, Ref. [5] found a correlation between qualitative concept knowledge of objects and the quality of completing sorting tasks for objects of different sizes. Regarding cosmology aspects, it has been shown that the Big Bang "being an explosion or the age of the universe being infinite are just some of the major misconceptions" [22] (p. 56) apparent among learners prior to instruction (see [23] as well). In the case of astrobiology, students have been shown to have, in part, adequate rough ideas about the topic, though not all, and they lack more in-depth understanding [24].

2.2. Learners' Conceptions of the Nature of Science

In order to foster a comprehensive and accurate representation of science to their students, (preservice) physics teachers must possess an understanding not only of the subject matter but also of the Nature of Science. As a result, numerous studies have been conducted over the past few decades to evaluate teachers' proficiency in this area.

These studies, however, have shown that a substantial part of the teachers possess a rather inadequate understanding of (aspects of) the Nature of Science [25,26]. For example, Abd-El-Khalick and Boujaoude [25] showed that incorrect ideas about the scientific concept of theory were prevalent (59% of the study's participants provided inadequate responses). In general, many people tend to have ideas about a false hierarchical structure between the ideas of hypothesis, theory and law [27]. Specifically in the astronomy context, it was found that the stronger one's religious beliefs, the less accepted the Big Bang theory is [28]. Furthermore, understanding of science and its methods and processes for knowledge acquisition was found to be often only developed at a surface level [25]. One area where the aforementioned findings intersect is the conception that astrology would be a legitimate scientific discipline, as evidenced by the views held by physics teachers in India [29].

3. Research Questions

So far, no studies have been published (to the best of our knowledge) that explore the conceptions of preservice physics teachers regarding astronomy and, in this context, the Nature of Science in Germany. The need to fill this research gap arises—as explained in the introduction—from curricular developments on the one hand and the great interest of learners in astronomical questions on the other.

With the investigation reported here, the previous state of research, which is quite extensive in the international literature, is supplemented by addressing the following research questions:

1. What are preservice physics teachers' conceptions of theories and knowledge acquisition in the context of astronomy?
2. What are preservice physics teachers' conceptions of selected concepts from inside and outside the solar system?

To have a broad cover of concepts regarding Research Question 2, several topics that have previously proven useful were selected (cf. [5,15]): size and distance of celestial objects, the Big Bang, basic orbital mechanics, difference between astronomy and astrology and life beyond Earth.

4. Methodology

4.1. Study Design and Sample

We conducted an exploratory survey study. No prior intervention was included. The sample comprises $N = 22$ preservice physics (secondary school) teachers from two German universities who have formally completed elective modules on astronomy, including 17 male and 4 female participants, as well as one nonbinary participant. The instrument described in the next subsection was administered in a pen-and-paper format. Data collection took place in May 2022.

4.2. Instrument

The instrument used in this study consists of seven tasks that were adopted for use in the German setting from the "Norwegian Introductory Astronomy Questionnaire" [5,15]. The content validity of our German version of the instrument was checked via expert feedback from three faculty members.

Two of the seven tasks were rank ordering tasks to assess the preservice teachers' conceptions regarding astronomy objects' sizes and distances from Earth. Moreover, since vignette tasks have been found to be fruitful in surveys in many ways [5,15,30,31], the remaining five tasks were presented in a vignette format to assess preservice teachers' conceptions of different astronomy concepts in- and outside the solar system (see Research Question 2).

Among the five vignette tasks, two addressed students' conceptions of Nature of Science aspects (see Research Question 1): One (Vignette 1, see Appendix A) addressed preservice teachers' views of the Big Bang theory, and hence, students' answers provided insights into their conceptions of theories in science more generally. The other one (Vignette

2, see Appendix A) addressed knowledge acquisition methods and techniques in the context of astronomy. The whole instrument is provided in the Appendix A.

4.3. Data Analysis

The software MAXQDA was used for data analysis (https://www.maxqda.com/, accessed on 6 May 2023). This software was used for qualitative content analysis according to [31]. The categories were formed inductively from the data and are presented in the results section of this article. All categories were treated equally in the coding process, and any subsequent occurrences of the same category in a participant's transcript were not coded, as they did not yield new insights into the participant's conceptions. Frequency analysis was utilized to count the number of occurrences of each category. The categories alongside coding rules and anchor examples are provided in Section 5.

All participants' responses were coded by independent raters, and Cohen's κ was calculated as an estimator of inter-rater reliability. The Cohen's κ values for the categorizations ranged from $\kappa = 0.70$ to $\kappa = 1.00$ for the five vignette tasks, which corresponds to "substantial" to "almost perfect" agreement [32]. In the analysis of the rank ordering tasks, firstly, a differentiation was made between correct and incorrect answers. Subsequently, subcategories were formed to analyze the incorrect answers in more detail (see Section 5).

5. Results

5.1. Results of Vignette Tasks

5.1.1. Vignette 1: Preservice Teachers' Conceptions Regarding Big Bang Theory

The first vignette presented a student discussion about the Big Bang theory, and the responses varied. Ten participants understood the concept of theory as provisional, and they attributed limited validity to the theory. Two participants saw theories as parts of a hierarchical structure, and two responses addressed the quality or proof of a theory. However, ten participants did not answer the question. A comprehensive overview of the categories of students' conceptions that emerged from our analysis is provided in Table 1.

Table 1. Categories (alongside coding rules and anchor examples) that emerged from students' responses to vignette task 1 regarding the meaning of theories in science, as well as the absolute frequencies of their occurrences.

Category	Coding Rule	Anchor Example	Absolute Frequency
Theories subject to temporal change and limited validity	Assignment to this category occurs if a participant acknowledges in some way that theories do not necessarily correspond to truth but must be understood as attempts to explain, or if the provisional nature of a theory is discussed.	"Theories are changeable and improve over time or are discarded."	10
Hierarchical structure	An answer is assigned to this category if a participant views theory as part of a hierarchical structure.	"Theories come first, then it is determined through testing whether they can become laws."	2
Different quality theories	An answer is assigned to this category if a participant discusses the quality or evidence of a theory.	"There are good and bad theories. The theory of a flat earth is bad, the theory of relativity is good."	2
No explanation	If a participant does not address the concept of theory, their answer is assigned to this category.	-	10

Four participants believed that the Big Bang was the beginning of the universe. Two responses mentioned a time before the Big Bang, and four described phenomena explained by the Big Bang theory. One participant noted that looking into distant objects is looking into the past. Thirteen participants did not address the Big Bang theory. A comprehensive overview of the categories of students' conceptions that emerged from our analysis is provided in Table 2.

Table 2. Categories (alongside coding rules and anchor examples) that emerged from students' responses to vignette task 1 regarding concepts about the Big Bang, as well as the absolute frequencies of their occurrences.

Category	Coding Rule	Anchor Example	Absolute Frequency
Beginning of the universe	An answer is assigned to this category if the student believes that the Big Bang is the beginning of the universe.	"At the beginning of time, there was the Big Bang."	4
Observable phenomena	An answer is assigned to this category if it includes phenomena that explain the Big Bang theory.	"The Big Bang can be traced through background radiation."	4
Not beginning of the universe	An answer is assigned to this category if it allows for a moment before the Big Bang.	"Before the Big Bang, everything was compressed together."	2
Looking into the past	An answer is assigned to this category if it includes looking into distant distances as looking into the past.	"By looking far into the distance, you can also look back to the Big Bang."	1
No reference to Big Bang theory	An answer is assigned to this category if a subject has not addressed the Big Bang theory.	-	13

5.1.2. Vignette 2: Preservice Teachers' Conceptions Regarding Experimental Methods Used in Astronomy Research

Regarding the methods used to gain new information in astronomy, eighteen participants stated that only one method (usually using telescopes) was used. Only three participants said that several methods were used. One person did not provide an answer. A comprehensive overview of the categories of students' conceptions that emerged from our analysis is provided in Table 3.

Table 3. Categories (alongside coding rules and anchor examples) that emerged from students' responses to vignette task 2 regarding the variety (in terms of numbers) of methods astronomers use, as well as the absolute frequencies of their occurrences.

Category	Coding Rule	Anchor Example	Absolute Frequency
Single method	An answer is assigned to this category if the student's opinion includes that in astronomy, mainly telescopes or another single method exist.	"Telescopes are used for observations in astronomy."	18
Variety of methods	An answer is assigned to this category if its core statement includes that astronomy uses multiple methods.	"In astronomy, various methods are used to learn about space."	3
No answer	An answer is assigned to this category if it does not contain any statement about the variety of methods.	-	1

Refractor telescopes (mentioned by seven participants) and various telescopes (mentioned by eight participants) were the most frequently cited methods telescopes worked by. Only one person mentioned reflector telescopes as a research instrument in astronomy. A comprehensive overview of the categories of students' conceptions that emerged from our analysis is provided in Table 4.

The main purpose of a telescope, according to ten participants, was to enlarge objects and phenomena, while four mentioned the ability to capture light. However, four participants who cited telescopes as scientific instruments did not elaborate on their functioning. A comprehensive overview of the categories of students' conceptions that emerged from our analysis is provided in Table 5.

Table 4. Categories (alongside coding rules and anchor examples) that emerged from students' responses to vignette task 2 regarding the methods astronomers use, as well as the absolute frequencies of their occurrences.

Category	Coding Rule	Anchor Example	Absolute Frequency
Various types	An answer is assigned to this category if it discusses different types of telescopes.	"There are different types of telescopes, such as reflecting and refracting telescopes."	8
Refractor telescopes	An answer is assigned to this category if it includes a statement about refracting telescopes.	"I believe the most commonly used telescopes are refractor telescopes."	7
Reflecting telescopes	An answer is assigned to this category if it includes a statement about reflecting telescopes.	"The most commonly used telescopes are reflecting telescopes."	1
No answer	If a subject does not give an answer, it is assigned to this category.	-	1

Table 5. Categories (alongside coding rules and anchor examples) that emerged from students' responses to vignette task 2 regarding concepts of the purpose of the use of telescopes in astronomy, as well as the absolute frequencies of their occurrences.

Category	Coding Rule	Anchor Example	Absolute Frequency
Magnification	An answer is assigned to this category if it includes the magnification effect of telescopes.	"Telescopes can magnify objects."	10
Light capture	An answer is assigned to this category if it includes the statement that telescopes are supposed to capture light.	"Telescopes capture a lot of light, so you can see difficult-to-observe objects."	4
Function not explained	An answer is assigned to this category if it does not explain the function of a telescope	-	4
No answer	If a subject does not give an answer, it is assigned to this category.	-	1

5.1.3. Vignette 3: Preservice Teachers' Conceptions Regarding Earth's Orbit

Regarding the stability of the Earth's orbit around the Sun, almost all participants used Newton's law of gravitation to argue their point. One person used the concept of curved space and another used velocities. Only one person did not provide an explanation. Eight participants used force equilibrium to provide a more detailed explanation, while five participants used the attraction of two bodies, and three used the attraction of large masses. Two participants believed that gravitational force only comes from a mass difference, and one person mentioned a force that acts in the direction of the Earth's motion. A comprehensive overview of the categories of students' conceptions that emerged from our analysis is provided in Table 6.

5.1.4. Vignette 4: Preservice Teachers' Conceptions Regarding Astronomy and Astrology Differentiation

In the vignette discussing the difference between astronomy and astrology, most participants responded that the two ideas were different. Two participants did not provide an answer. Two participants described astrology as a science, and sixteen described it as a pseudoscience. Two participants did not elaborate on astrology. A comprehensive overview of the categories of students' conceptions that emerged from our analysis is provided in Table 7.

Table 6. Categories (alongside coding rules and anchor examples) that emerged from students' responses to vignette task 3 regarding concepts about the stability of Earth's orbit, as well as the absolute frequencies of their occurrences.

Category	Coding Rule	Anchor Example	Absolute Frequency
Newton	An answer is assigned to this category if it includes an argumentation with Newton's law of gravity.	"The Earth stays on its orbit according to Newton's law."	19
Curved space	An answer is assigned to this category if it describes the curvature of spacetime by masses as the cause of gravity.	"The Earth flies in a circular orbit due to the curvature of space."	1
Velocity-dependent	If an explanation refers to velocity, it is assigned to this category.	"The velocity of the Earth is just right so that it doesn't fly away or fall into the Sun."	1
Force equilibrium	An answer is assigned to this category if it includes an explanation of the balance between centripetal and centrifugal forces.	"The centripetal and centrifugal forces of the Earth are in equilibrium."	8
Mutual attraction	An answer is assigned to this category if it includes the attraction between bodies without direct reference to mass or similar parameters.	"That is because the Sun attracts the Earth."	5
Large masses attract	A statement that large masses attract smaller masses is assigned to this category.	"The Sun has a large mass and therefore attracts the small Earth."	3
Gravitation due to mass difference	An answer that states that gravity only acts between bodies of different masses is assigned to this category.	"The mass difference between the Earth and the Sun causes the Earth to be attracted by the Sun and guided onto a circular path."	2
Force in the direction of motion	An answer that includes a force in the direction of the Earth's motion is assigned to this category.	"The Earth always has a force due to its motion that keeps it on its trajectory."	1
No explanation	If no explicit explanation is given in the answer, it is assigned to this category.	-	1

Table 7. Categories (alongside coding rules and anchor examples) that emerged from students' responses to vignette task 4 regarding concepts about astrology as a science, as well as the absolute frequencies of their occurrences.

Category	Coding Rule	Anchor Example	Absolute Frequency
Astrology as a pseudoscience	An answer is assigned to this category if it describes astrology as a pseudoscience.	"Astrology is a pseudoscience without proven hypotheses."	16
Astrology as a science	An answer is assigned to this category if it describes astrology as a science.	"Astrology is the science of celestial bodies and zodiac signs."	2
No answer	If a participant does not provide an answer, their response is assigned to this category.	-	2

5.1.5. Vignette 5: Preservice Teachers' Conceptions Regarding Life Beyond Earth

In the vignette task on "life on other planets/celestial objects", almost all participants (20 out of 22) answered with a positive outlook regarding the possibility of alien life. Twelve people argued using statistics and the multitude of existing stellar systems, four people referred to the discovery or existence of other habitable planets and three people argued that proving the opposite is difficult to impossible. Two people also referred to clues that speak in favor of life beyond earth that have been found so far. A comprehensive overview of the categories of students' conceptions that emerged from our analysis is provided in Table 8.

Table 8. Categories (alongside coding rules and anchor examples) that emerged from students' responses to vignette task 5 regarding concepts about life beyond Earth, as well as the absolute frequencies of their occurrences.

Category	Coding Rule	Anchor Example	Absolute Frequency
Statistical probability	If an answer argues with a high probability based on a large number of galaxies, it is assigned to this category.	"With so many star systems, why shouldn't there be other inhabited planets?"	12
Habitable planets	An answer is assigned to this category if it addresses habitable planets.	"There are other habitable planets, why shouldn't there be life there?"	4
Proof of the opposite	If an answer claims that it is difficult to prove the opposite, it is assigned to this category.	"You can't prove that there is no life elsewhere!"	3
Clues	If an answer addresses previously found clues for life, it is assigned to this category.	"We have even found evidence of life outside of Earth."	2
Other explanation	If an answer uses a different argumentation than the above categories, it is assigned to this category.	"Life is everywhere because otherwise... I am afraid of emptiness."	1

5.2. Results of Rank Ordering Tasks

In rank ordering task 1, all participants correctly ranked the sizes of the objects "galaxy, planet, star, universe, solar system" in order.

In the question about the ranking of different objects and places at varying distances (rank ordering task 2), only 7 students sorted all objects correctly. The most common confusions are shown in Figure 1.

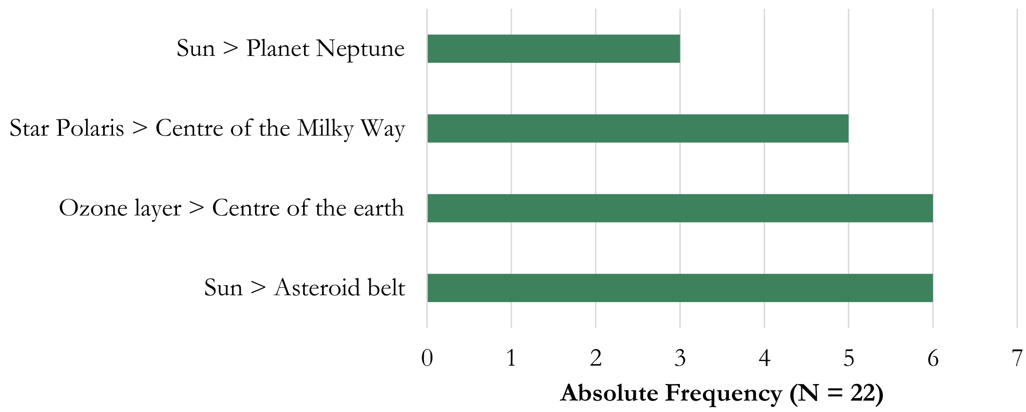

Figure 1. Most common mistakes in arranging typical objects in terms of distance from the Earth's surface that were identified in rank ordering task 2. The absolute frequency of cases in which the object to the left of the ">" symbol was considered to be further away from the Earth's surface than the object to the right of the symbol is given.

6. Discussion

With the discussion of the results, Research Question 1 (conceptions of the theories in science) and Research Question 2 (typical conceptions of astronomy concepts) are answered within the framework of the conducted questionnaire study.

6.1. Discussion of Research Question 1: Preservice Teachers' Conceptions of Theories and Knowledge Acquisition in Science

The vignette tasks serve to identify conceptions of the concept of theory and knowledge gain in science. For this purpose, conceptions of well-known physical theories such as the Big Bang theory or Newton's gravitational theory are determined. Most participants explain that a theory does not necessarily correspond to the truth but is accepted if there are many indications in favor of it. This leaves open the possibility of falsification. This understanding comes closest to the concept of theory in the natural sciences, according to which every knowledge possesses only a provisional character. Nevertheless, two participants have an everyday understanding of the concept of a theory, in which they see it as part of a hierarchical structure and that it can easily change with new evidence gained. This finding confirms the research by [27] that even preservice physics teachers still have everyday conceptions of the general concept of a theory. Additionally, taking the case of the Big Bang, it was found by [28] that religious beliefs may influence the strength of preservice teachers' acceptance of the Big Bang theory. As religious beliefs were not part of the questionnaire, it is not clear how much this had an influence on the results presented in this study.

Based on selected theories, participants' conceptions of these are determined. One of these theories is the Big Bang theory. In vignette task 1, it was not explicitly demanded that the Big Bang theory should be addressed. We suspect that this is the reason why the category "No explanation" is so pronounced. At the same time, it is noticeable that two students write about a time before the Big Bang and that the universe must have already existed in a compressed form. This corresponds to an everyday understanding of this theory, as time is always assumed to exist, even before the Big Bang. The scientific view is that time and the universe itself began only with the Big Bang. This shows that even among the participants, there are everyday conceptions of the Big Bang.

6.2. Discussion of Research Question 2: Preservice Teachers' Conceptions of Astronomy Concepts

The participants were asked to evaluate astronomy and its methods. In doing so, we can show that 18 students reduced astronomy to a single method. Therefore, incomplete conceptions of this subfield of physics are dominant. Analogous findings are seen in the conceptions of the functioning of telescopes. Ten participants reduced the functions of telescopes to the magnification of images. This misconception is also described by [33]. The main task of telescopes, however, is to capture electromagnetic radiation.

As expected, half of the participants know that there are different types of telescopes, such as refractor or reflector telescopes. However, over a third of the participants believe that refractor telescopes are exclusively used in astronomy. This finding is consistent with studies by [33].

A central theory in astronomy deals with gravity. Using the example of the movement of the Earth around the Sun, students were asked to explain the cause of the Earth's orbit. As expected, many participants argued with Newton's law of gravitation. This is not surprising, as this theory is extensively covered in introductory lectures. In contrast, the general theory of relativity, which one participant used to explain the Earth's orbit, is not canonically included in the teacher training program of the participants.

Because so many students argued with Newton's theory, the authors decided to further investigate the misconceptions regarding this theory. They found that three participants believed that only large masses attract small masses. Two other participants explained that gravitational force only occurs between objects of different weights. Additionally, eight students held the misconception that there is a balance of gravitational and centrifugal forces. Ref. [34] also diagnosed this misconception. Furthermore, one participant drew a force in the direction of the Earth's motion, which corresponds to the misconception that a force is necessary to maintain the movement. Therefore, it can be concluded that almost three-quarters of the participants held misconceptions regarding Newton's law of gravity. In the original study using the questionnaire by [5,15], argumentation with the conservation of energy was found, which was not replicated in this study.

In vignette task 4, the students were asked to position themselves on the difference between astrology and astronomy. No participant answered that the two disciplines are the same. This result differs greatly from a study by Robertis and Delaney, which was conducted in Canada. They found that 44% of students could not distinguish between astronomy and astrology [35]. In a 2011 American study, Sugarman et al. found that over 70% of students believed that astrology was, at least in part, a scientific discipline [36].

Because two participants do not provide a justification for their decision, according to our study, 20 out of 22 participants believed that astrology and astronomy are different disciplines. Furthermore, 16 students considered astrology to be a pseudoscience. Only two participants saw astrology as a science. We notice that the participants had incorrect ideas about astrology. For example, one respondent was of the opinion that astrology deals with the solar system. Overall, we can conclude that the participants had a very good understanding of the difference between astrology and astronomy.

Vignette task 5 deals with the question of extraterrestrial life. The majority of students believed that there is life elsewhere in the universe. Only two had a different opinion. However, it turns out that one of these two participants argued for the opposite side. He wrote that we know of several planets that orbit in the habitable zone of their star. We cannot judge whether the participant confused the two students in the vignette when answering his question. We then examined the ideas of the participants who agree with student A's answer more closely. Four students mentioned habitable zones around stars in their justification. However, it turns out that the most common answer is related to statistical probability due to the large number of stars and galaxies. Other participants also mention the fact that evidence of life has already been found on other planets, or the idea that the existence of life is irrefutable. An answer regarding proof of alien life through UFO sightings as in [5,15] was not found.

Another goal of the tasks is to identify students' ideas about astronomical objects. The focus is on the scale of the size and length of objects beyond our solar system. In rank ordering task 1, all participants correctly assigned the given astronomical objects. This result aligns with the findings by [5]. In their study [5], a mean score of 91.6% was achieved in this rank ordering task after instruction. Moreover, it was found that about 15% of preservice teachers would classify a solar system larger than a galaxy without prior intervention. After the instruction, this dropped to only 5%.

In rank ordering task 2, participants were asked to sort different objects according to their distance from the Earth's surface. Overall, only one-third of the participants could sort all objects correctly. Confusing the Sun as being further away from Earth is equally common as confusing the asteroid belt as being further away from Earth than the ozone layer or the center of the Earth. In both cases, the absolute frequency is six. Additionally, five students stated that the Pole Star (Polaris) is further away from the Earth's surface than the center of the Milky Way. Furthermore, three participants wrote that the Sun is further away from the Earth's surface than the planet Neptune. This result also coincides with the findings from [5]. Moreover, one participant stated that the answer would "depend on how close it flies by." This suggests a flawed idea about the asteroid belt.

7. Limitations

There are three major limitations associated with this study that need to be taken account: Firstly, the sample size of our study is naturally limited, as we only included preservice physics teachers who had formally completed astronomy courses at their university. While this allowed us to control for the study sample, it restricted the population of potential study participants in terms of both number and diversity.

Secondly, astronomy lectures or seminars are not an obligatory part of physics teachers' education programs. Therefore, our study participants represent a positive selection, and we suggest that future research should focus on in-service physics teachers' astronomy conceptions to obtain a more comprehensive understanding. Nonetheless, we believe that our findings may inform the development of teacher training courses on astronomy topics.

Thirdly, in our study, we used both vignette and rank ordering tasks to assess preservice physics teachers' conceptions of astronomy concepts. However, as noted by [5], the usefulness of the ranking task is limited if students achieve a near-perfect score, as this does not guarantee that students have satisfactory qualitative knowledge. In our study, all participants succeeded in ranking the different astronomy objects' sizes, and thus, the task does not allow us to draw conclusions about the in-depth qualitative knowledge among our participants. However, this was not the primary focus of our study, and further research could use more suitable instruments for investigating the apparent conceptions in the population under investigation (cf. [37]).

8. Conclusions

In the study presented in this article, we identified some of the ideas held by preserivce physics teachers regarding astronomical objects, laws and theories. Our findings have direct implications for astronomy teaching and learning practices: On the one hand, our results underline that it seems "more important to focus on helping students learn what the objects are (i.e., qualitative knowledge) instead of focusing primarily on size and distance during instruction" [5] (p. 16), since the study participants struggle in giving elaborate explanations of different astronomy concepts while succeeding in ranking astronomy objects in terms of their sizes. Implementation of proven but not yet commonly used approaches to teaching might help university students and preservice teachers to get a more refined understanding of these topics. There have been several approaches that showed a lot of promise in this regard, such as using games and plays [38] or real data [39–41] to improve learning. On the other hand, our study uncovers underdeveloped conceptions among some of the preservice physics teachers regarding theories in the context of astronomy.

Hence, in future research, it seems sensible to investigate how teaching about fundamental ideas of astronomy might mediate learning about what scientific theories in particular are and about the Nature of Science more generally.

The aspects of Nature of Science, and especially how astronomers use modeling as a tool to gain new knowledge, have been indicated to be more effectively understood by using model-based learning instead of more traditional reproductive learning [42] and might be useful to be implemented, tested and taught in astronomy education courses.

In this regard, in future research, we will revise the study presented here with a larger sample of in-service teachers and graduate students from various universities in order to derive design principles for teacher training courses on astronomy in order to foster physics teachers' (pedagogical) content knowledge regarding astronomy.

Author Contributions: Conceptualization, M.S.U. and P.B.; methodology, M.S.U. and P.B.; formal analysis, F.H. and M.L.; investigation, M.L.; data curation, F.H. and M.L.; writing—original draft preparation, F.H.; writing—review and editing, F.H., M.L., M.S.U. and P.B.; supervision, P.B. All authors have read and agreed to the published version of the manuscript.

Funding: We acknowledge financial support by Deutsche Forschungsgemeinschaft and Friedrich-Alexander-Universität Erlangen-Nürnberg within the funding programme "Open Access Publication Funding".

Institutional Review Board Statement: Ethical review and approval were waived for this study due to the fact that the study was in accordance with the Local Legislation and Institutional Requirements: Research Funding Principles (https://www.dfg.de/en/research_funding/principles_dfg_funding/research_data/index.html) and General Data Protection Regulation (https://www.datenschutz-grundverordnung.eu/wp-content/uploads/2016/04/CONSIL_ST_5419_2016_INIT_EN_TXT.pdf (accessed on 7 April 2023).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study to publish this paper.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

In this appendix, the instrument used in this study is provided in the English language.

Appendix A.1. Vignette Tasks

All of the following vignette tasks are taken from [5]:

- Vignette 1: A group of year-9 students is having an argument. Student A: "I accept that the universe started with the Big Bang." Student B: "I don't believe in the Big Bang as its just a theory." Student C: "Alright, but then why do so many scientists seem to accept it?" Write down in detail what you will say to these students in order to settle their argument.
- Vignette 2: A year-9 student asks you: "How do astronomers learn things about the universe? I know they primarily use telescopes, but what do the telescopes actually do?" Write down what you will tell this student.
- Vignette 3: You overhear a group of year-9 students having a discussion. Student A: "I am always amazed that Earth just keeps going round and round the sun!" Student B: "Yes! How come it goes round and round and doesn't just fly off into space?" Student C: "Actually, I wonder the opposite: why doesn't Earth just spiral into the sun?" Explain to the group, possibly with the aid of a diagram, how they should think about this.
- Vignette 4: A group of year-9 students is having an argument. Student A: "There is no difference between astronomy and astrology." Student B: "Nonsense! Astronomy and astrology are totally different." Student C: "They might be different but they are equally useful." Write down in detail what you will say to these students in order to settle their argument.
- Vignette 5: Two year-9 students are having an argument. Student A: "There is no life anywhere in the universe other than on Earth!" Student B: "I disagree. There has to be life elsewhere in the universe." With whom do you most closely agree?

Appendix A.2. Rank Ordering Tasks

All of the following rank ordering tasks are taken from [5]:

- Rank ordering task 1: Rank the following from smallest to largest: galaxy, planet, star, universe, solar system.
- Rank ordering task 2: Rank the following by their distance from the Earth's surface: centre of the Milky Way, edge of the observable universe, the asteroid belt, edge of the solar system, the Moon, the Sun, the star Polaris, the ozone layer, centre of Earth, Neptune.

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