Chapter 9
Investigating Relationships Between Epistemological Beliefs and Personal Beliefs in Biological Evolution

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9.1 Introduction

Evolution is widely seen as the central, unifying and overarching theory in biology. The field of biology is made up of many broad topics threaded and held together by the theory of biological evolution. For example, content related to evolutionary theory can include anything that refers to organisms' adaptation to their environment and/or ability to survive and create offspring. It includes DNA, protein sequences, common ancestry, genetic variation of populations of organisms, fossils and plant and/or animal diversity. Therefore, educating students about biological evolution is vitally important because it is capable of explaining a large number of natural phenomena at different levels. In addition, an understanding of biological evolution is becoming increasingly relevant in practical contexts, including medicine, agriculture, and resource management (Dunk & Wiles, 2018; Fowler & Zeidler, 2016).

Despite the importance of biological evolution, it is still poorly understood by students throughout their time in education (Nehm & Reilly, 2007; Shtulman, 2006; Spindler & Doherty, 2009), science teachers, and the general public (Baytelman et al., 2023; Evans et al., 2011). This poor understanding has been attributed to diverse cognitive, epistemological, religious, and emotional factors (Rosengren et al., 2012) that evidently biological evolution education is generally not successfully coping with.

Previous research suggests a connection between students' acceptance and understanding of evolutionary theory and their epistemological beliefs toward

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science. In particular, previous research has shown that there are relationships between students' sophisticated epistemological beliefs toward science and their acceptance and understanding of evolutionary theory (Borgerding et al., 2017; Mazur, 2005; Sinatra et al., 2003). On the other hand, it has been argued that a firm grasp of epistemological beliefs allows students to compare knowledge frameworks, in order to understand how and why knowledge produced through science is different from their religious beliefs. Additionally, students' (and other individuals') personal beliefs define how they view the world, which in turn can influence their learning, views of science and academic performance. Numerous studies have identified difficulties in learning about biological evolution throughout education, and there is evidence that some of these difficulties stem from epistemological beliefs, personal beliefs and cognitive biases (Cavallo & McCall, 2008; Harms & Reiss, 2019; Shtulman & Calabi, 2012; Shtulman & Schulz, 2008; Sinatra et al., 2003). The possible relationship between 12th grade students' epistemological beliefs toward science and their personal beliefs in biological evolution could be of interest to researchers, educators and biology teachers in the field, but has not yet been enough investigated.

In the present study, we address this gap in the literature, namely whether and to what extent 12th grade students' epistemological beliefs toward science can predict their personal beliefs in biological evolution, before biological evolution instruction. Based on previous research (Sinatra et al., 2003; Sinclair & Baldwin, 1996), we hypothesized that there would be a relation between students' epistemological beliefs toward science and their personal beliefs in biological evolution, before instruction. By doing this, we hope to gain a better understanding of the contribution of students' epistemological beliefs toward science to their beliefs in biological evolution, before instruction, and contribute to the development of a theoretical framework that will describe learning about biological evolution throughout education. Then, additional research could benefit from this study's findings to measure the possible interaction of these two concepts with students' understanding and acceptance of biological evolution.

In particular, we set out to answer the following research question: What are the relationships between 12th grade students' epistemological beliefs toward science and their personal beliefs in plant evolution, animal evolution and human evolution, before biological evolution instruction?

9.1.1 Conceptualization of Epistemological Beliefs

According to Kitchener (2002), epistemology is a theory of knowledge and how it develops, while personal epistemology is a personal theory about how individuals develop knowledge.

Researchers who study epistemology are interested in "*how individuals come to know, the theories and beliefs they hold about knowing, and the manner in which*

such epistemological premises are part of and have an influence on the cognitive processes of thinking and reasoning" (Hofer & Pintrich, 1997, p. 88).

Epistemological beliefs refer to individuals' beliefs about the nature of knowledge and the process through which knowledge develops (Hofer & Pintrich, 1997). Different models have been proposed on how to conceptualize and examine epistemological beliefs. From these, two overarching kinds of models can be identified: (a) models that examine epistemological beliefs from a developmental perspective (Perry, 1970) and (b) models that explore epistemological beliefs from a multidimensional perspective (Hofer & Pintrich, 1997; Schommer, 1990).

Research on epistemological beliefs was initiated by Perry (1970). He found that students do have strong beliefs about knowing and knowledge, but they can change over time. Perry argued that students entering college perceive knowledge to be simple, certain, and provided by the instructor; however, upon graduation, the same students often held more sophisticated beliefs, viewing knowledge as complex, tentative, and derived from reason and observation. Perry proposed a developmental model that described nine levels in epistemological beliefs, ranging from the belief that knowledge is objective, to the belief that knowledge is radically subjective, and finally to the belief that knowledge has objective and subjective aspects.

Since Perry's research, perhaps one of the most influential studies in epistemological beliefs was conducted by Schommer (1990). Schommer suggested that students' epistemological beliefs consist of a collection of more or less independent beliefs (epistemological dimensions). Schommer proposed a multidimensional model and suggested five theoretical dimensions of epistemological beliefs: (a) the structure of knowledge (from the simple to the complex nature of knowledge), (b) the stability of knowledge (from the factual to the constantly changing nature of knowledge), (c) the source of knowledge (from the omniscient source to the empirically evidenced-based nature of knowledge), (d) the speed of learning (from the quick to the gradual nature of learning), and (e) the ability to learn (from the fixed or innate to the incremental nature of ability) (Cho et al., 2011).

While the dimensions of structure, stability, and source in Schommer's conceptualization fall under the more generally accepted definition of epistemological beliefs (Hofer & Pintrich, 1997), the speed and ability dimensions are controversial because they mainly concern beliefs about learning (speed) and intelligence (ability). Hofer and Pintrich (1997) argued that epistemological beliefs should be defined more purely, with two dimensions concerning the nature of knowledge (what one believes knowledge is) and two dimensions concerning the nature or process of knowing (how one comes to know).

According to Hofer and Pintrich (1997), the two dimensions concerning the nature of knowledge are: (a) Simplicity of knowledge (related to the structure of knowledge), ranging from the belief that knowledge consists of an accumulation of more or less isolated facts to the belief that knowledge consists of highly interrelated concepts, and (b) Certainty of knowledge (related to the stability of knowledge), ranging from the belief that knowledge is absolute and unchanging to the belief that knowledge is tentative and evolving. The two dimensions concerning the

nature of knowing are: (c) Source of knowledge, ranging from the conception that knowledge originates outside the self and resides in external authority, from which it may be transmitted, to the conception that knowledge is actively constructed by the person in interaction with others, and (d) Justification for knowing, ranging from justification of knowledge claims through observation and authority, or on the basis of what feels right, to the use of rules of inquiry and the evaluation and integration of different sources (Hofer & Pintrich, 1997). Accordingly, Hofer and Pintrich's model differs from Schommer's by omitting the nature of learning factors and adding another nature of knowing factor: Justification.

Additionally, Conley et al. (2004) suggested a new dimension of epistemological beliefs, i.e., the Development of knowledge, which is related to the nature of the development of knowledge. Researchers in the field of epistemology, educational psychology and science education have proposed a variety of instruments for the examination of epistemological beliefs (e.g., Baytelman, 2015; Baytelman et al., 2020a, b, 2022; Baytelman & Constantinou, 2016a, b; Conley et al., 2004; Kuhn et al., 2000; Schommer, 1990; Schommer et al., 1992; Schommer-Aikins, 2004). The Dimensions of Epistemological Beliefs toward Science (DEBS) Instrument (Baytelman et al., 2020a, b, 2022; Baytelman & Constantinou, 2016a, b) is based on the multidimensional perspective of epistemological beliefs and captures five dimensions: three dimensions related to the nature of knowledge (Certainty, Simplicity and Development of Knowledge), and two dimensions related to the nature of knowing (Source and Justification of Knowledge). The DEBS Instrument is suitable for high school and university undergraduate students and was used for this study.

Despite the differences between the developmental and the multidimensional models, "*the fairly well-established trend is that individuals move from some more objectivist perspective through a relativistic one, to a more balanced and reasoned perspective on the objectivist–relativistic continuum, with this latter position reflecting a more sophisticated manner of thinking"* (Pintrich, 2002, p. 400).

According to Muis et al. (2015), since the multidimensional model of epistemological beliefs is a system of more or less independent epistemological dimensions which are not necessarily developing in synchrony with each other, it is important to make efforts to foster all dimensions of students' epistemological beliefs, using a variety of didactical approaches. Some recommended didactical approaches to promote students' epistemological beliefs are inquiry-based teaching and learning (Shi et al., 2020), teaching and learning using history of science (Matthews, 1992, 1994) dialogic argumentative activities (Baytelman, 2015; Baytelman et al., 2020a; Iordanou & Constantinou, 2014) and reflective judgment through socioscientific issues (Zeidler et al., 2009). However, the recommended didactical approaches are synergistic, built upon one another, and provide opportunities for fostering students' epistemological beliefs.

Researchers have argued that epistemological beliefs are related to learning and academic performance, comprehension, views of science, innate learning and choosing science as a career, self-efficacy beliefs, students' motivation and higher levels of self-concept and self-efficacy (Baytelman et al., 2023; Chen, 2012).

Additionally, studies argue that students' epistemological beliefs have a direct impact on the selection of learning strategies or approaches, the process of shaping conceptions, and problem-solving (Chan et al., 2011) and an individual's ability to generate alternative arguments, counterarguments and rebuttals (Baytelman et al., 2020a).

9.1.2 Personal Beliefs in Biological Evolution

Personal beliefs in a construct (e.g., biological evolution) are considered to be personal truths or personal views of the world. These personal truths are not held to the same epistemological criteria as knowledge; instead, personal beliefs are understood to be extra-rational. In other words, they are not based on the evaluation of evidence, they are subjective, and they are often intertwined with affect (Sinatra et al., 2003).

Personal beliefs in biological evolution are based on personal convictions, opinions, and degree of congruence with other belief systems, and are very resistant to change, despite instruction. Students' worldviews are sculpted mainly by culture, religion, politics and education (Mazur, 2005). Many times these beliefs influence students to place themselves in an either/or position in regard to evolution (Sinclair & Baldwin, 1996). These positions seem to fall into one of two camps: evolutionist or creationist. Evolutionists tend to believe that evolution is a process of change that is independent of the influence of any supreme design, while creationists tend to believe that there is some supreme force directing the development of life. These differing beliefs can affect how students approach learning evolution (Cavallo & McCall, 2008). One of the most influential factors regarding one's beliefs appears to be religion. Religious beliefs seem to contribute to the variation in student beliefs in biological evolution. Religion is a very personal aspect of one's life, and beliefs in general are a very personal aspect of viewing the world. Therefore, it stands to reason that religion can be an influence on beliefs about controversial topics such as biological evolution (Cavallo & McCall, 2008). In general, personal beliefs are shown to interfere with the students' ability to examine scientific evidence objectively, and the interference can be even stronger when learned religious ideas are against the information being taught (Cavallo & McCall, 2008; Sinclair & Baldwin, 1996).

Students have likely been exposed to some opinions about evolution from parents, religious leaders, or the media before entering the classroom. This exposure has most likely helped form ideas and beliefs in evolution prior to formal biological evolution instruction (Shtulman & Schulz, 2008; Woods & Scharmann, 2001). This suggests that biology teachers need to explore their students' worldviews and personal ideas in biological evolution before instruction, and explore how their personal beliefs may be impacted by science teaching and learning. Blackwell et al. (2003) highlight that evolutionary theory remains a topic that will often require penetration into a person's belief system prior to acceptance.

In an explanation of the role of emotions and epistemology when students learn biological evolution, Scharmann (1990) has suggested that students need to be aware that consideration of biological evolution does not require that they turn away from their firmly entrenched religious beliefs and culturally-based understandings. Yet, he has suggested that a diversified strategy that targets not only constructs related to biological evolution, but also focuses on students' understanding of the nature of scientific knowledge, allows for students to consider scientific concepts without forcing them to turn from their religious and cultural beliefs.

Additionally, Sinatra et al. (2003) have argued that a firm grasp of epistemological beliefs allows students to compare knowledge frameworks, to understand how and why knowledge produced through science is different from their religious beliefs. Yet, Cherif et al. (2001) found a strong relationship between beliefs and understanding of biological evolution. However, biology education currently has an incomplete understanding of potential relationships between students' epistemological beliefs toward science and personal beliefs in biological evolution.

9.2 Research Design and Method

9.2.1 Study Design

The present study examines relationships between 12th grade students' epistemological beliefs toward science and their personal beliefs in plant evolution, animal evolution and human evolution, before biological evolution instruction. The aim of the study is a deeper understanding of the contribution of students' epistemological beliefs toward science to their beliefs in biological evolution, before instruction, and the development of a theoretical framework that will describe teaching and learning about biological evolution throughout education. In particular, we seek to answer the following research question: What are the relationships between 12th grade students' epistemological beliefs toward science and their personal beliefs in plant evolution, animal evolution and human evolution, before biological evolution instruction?

To answer our research question, we asked 12th grade students to respond to instruments (questionnaires and semi-structured interviews) that assess their epistemological beliefs toward science and their personal beliefs in plant evolution, animal evolution and human evolution, before biological evolution instruction.

The quantitative and qualitative data were collected in three stages: (a) First stage: Assessment of 51 participants' epistemological beliefs, using a questionnaire based on the multidimensional perspective of epistemological beliefs; (b) Second stage: Assessment of 51 participants' personal beliefs in animal, plant and human evolution, using a specific questionnaire; (c) Third stage: Conducting semi-structured interviews with five participants. The interview guidelines made specific reference to the questionnaire in order to investigate further 12th grade students' epistemological beliefs and personal beliefs in biological evolution and obtain a

more comprehensive understanding of them. The major purpose of using quantitative and qualitative approaches and methods of data collection was to increase their validity and credibility (Greene, 2007).

9.2.2 Participants

In this study, participants included 51 12th grade students at a public secondary school in Cyprus, (female 31, male 20, with a mean age of 17.5 years). In Cyprus, 12th grade students have biology as an elective course. The unit on evolution is taught at the end of high school, and, according to the Cyprus National Curriculum, students do not have any lessons on biological evolution before grade 12. The participants were Caucasian native speakers of Cyprus and shared a homogeneous middle-class social background and the Greek language. They were of Christian affiliation, with the majority being Christian Orthodox. They attended the same school and came from the same geographical area of Cyprus. All instruments that were used for this study were in the Greek language, and all data were treated anonymously and confidentially.

9.2.3 Data Collection

Instruments In order to answer the research question (What are the relationships between 12th grade students' epistemological beliefs toward science and their personal beliefs in plant evolution, animal evolution and human evolution, before biological evolution instruction?), we used two different questionnaires and semi-structured interviews.

Participants' epistemological beliefs were assessed using the Dimensions of Epistemological Beliefs toward Science Instrument (DEBS) (Baytelman, 2015; Baytelman et al., 2020a, b; Baytelman & Constantinou, 2016a, b), which is based on the multidimensional perspective of epistemological beliefs and has been validated in the particular culture in which the research was conducted. This instrument contained 30 Likert-scale items designed to assess three dimensions concerning knowledge (i.e., Certainty, Simplicity and Development of knowledge), and two dimensions concerning knowing (i.e., Source and Justification of knowledge). Each dimension consisted of six items. Scoring of the DEBS was done by rating the 30 items on a four-point Likert scale, ranging from strongly disagree to strongly agree (strongly disagree = 1, disagree = 2, agree = 3, and strongly agree = 4). High scores on this measure represent more sophisticated epistemological beliefs, while low scores represent less sophisticated beliefs. The DEBS Instrument is suitable for high school and university undergraduate students (Baytelman, 2015; Baytelman et al., 2023).

Table 9.1 Main questions used in the semi-structured interviews

A/A	Main questions used in the semi-structured interviews
1	Do you believe that scientific knowledge and theories are reliable and unchanging? Please explain why or why not
2	Do you believe that in order to gain real insight into scientific issues it is necessary to form a personal opinion about what one reads/listens to, or to accept this information as reliable? Please explain why or why not
3	Do you believe that the plants that we know today have evolved from earlier species? Please explain why or why not
4	Do you believe that the animals that we know today have evolved from earlier species? Please explain why or why not
5	Do you think that human beings have evolved from earlier species? Please explain why or why not

To assess participants' personal beliefs in biological evolution, we used a specific instrument, namely the Personal Beliefs in Biological Evolution Instrument (PBBE), which was developed specifically for this study. This instrument contained four items designed to assess students' beliefs in plant evolution, animal evolution, human evolution, and human creation by God. Similarly to epistemological beliefs, each item was rated on a four-point Likert scale, ranging from strongly disagree to strongly agree (strongly disagree = 1, disagree = 2, agree = 3, and strongly agree = 4).

Interview Guidelines In order to triangulate and verify the findings of the data collected by the DEBS and PBBE Instruments, interviews were conducted. Interviews were semi-structured and conducted individually. In this part of the study, five 12th grade students (female 3; male 2) volunteered to participate in interviews, six days after they completed the DEBS and PBBE questionnaires, and before biological evolution instruction. In particular, five main questions were posed, supported by a number of sub-questions to help students elaborate on the topic if necessary. Interviews lasted 20 min each. The participants were all asked the same questions, but, in some cases, the manner in which they were asked varied, in order to obtain in-depth information (Bryman, 2008). Table 9.1 illustrates the main questions that were used in the semi-structured interviews.

9.2.4 Data Analysis

The quantitative data from the four-point Likert-scale questionnaires were analyzed statistically with the help of a computer-based statistical program: SPSS 20. First, the means, standard deviations, and the minimum and maximum scores of all variables of this study were calculated. Then, to investigate whether the variables of the study were positively or negatively and significantly correlated among them, Pearson correlations were calculated.

To answer whether the 12th grade students' epistemological beliefs can predict their personal beliefs in plant evolution, animal evolution and human evolution,

before biological evolution instruction, multiple regression analyses were carried out with epistemological beliefs (epistemological dimensions) as predictors. This approach enabled us to examine a relationship between dependent variables (personal beliefs in plant evolution, animal evolution and human evolution), and multiple independent variables (dimensions of epistemological beliefs), before biological evolution instruction.

Qualitative data from semi-structured interviews were analyzed through content analysis, using both inductive and deductive qualitative content analysis in order to develop coding categories (Mayring, 2000). The semi-structured interviews were audio recorded and transcribed. The content analysis of interview transcripts was conducted by two researchers who were familiar with epistemological beliefs and biological evolution. The content analysis was undertaken through a manual method of analysis. Coding categories emerged from students' data through repeated examination, comparison, and interpretation.

In the case of disagreements regarding content analysis of semi-structured interviews, the two coders discussed all discrepancies. Inter-rater reliability for the main questions of the semi-structured interviews was estimated using Cohen's Kappa, with $\underset{\sim}{k} = .91$.

9.3 Results

Table 9.2 displays the means, standard deviations, and the minimum and maximum scores of all variables of this study.

As seen in Table 9.2, participants' scores on the epistemological beliefs toward science measure suggested relatively sophisticated beliefs about the nature of knowing (source and justification of knowledge), and less sophisticated beliefs about the nature of knowledge (certainty [stability of knowledge], simplicity [structure of knowledge] and development of knowledge). Yet, participants' scores on their

Table 9.2 Descriptive statistics for all variables of the current study (N = 51)

Variable	M	SD	Min.	Max.
Epistemological beliefs				
Certainty of knowledge	2.59	0.39	1.33	3.16
Simplicity of knowledge	2.55	0.37	1.66	3.33
Development of knowledge	2.56	0.27	1.83	3.00
Source of knowledge	2.80	0.43	2.00	3.66
Justification of knowledge	2.90	0.34	2.16	4.00
Personal beliefs in biological evolution				
Beliefs in plant evolution	3.23	0.73	1.00	4.00
Beliefs in animal evolution	3.30	0.74	1.00	4.00
Beliefs in human evolution	2.65	0.79	1.00	4.00
Beliefs in human creation by God	3.41	0.92	1.00	4.00

personal beliefs in plant and animal biological evolution measure were higher than their scores on beliefs in human evolution. However, participants' scores on beliefs in human creation by God were the highest.

Table 9.3 displays the Pearson correlations between all variables of this study.

As seen in Table 9.3, the Pearson correlations indicated significant positive correlation (Cohen, 1988, 1992) between source epistemological beliefs before evolution intervention and personal beliefs in plant evolution and animal evolution ($r = .33$, $p < .05$; $r = .35$, $p < .05$), suggesting that more sophisticated epistemological beliefs about the source of knowledge were correlated with high personal beliefs scores on plant and animal biological evolution. The results of the Pearson correlations indicated no significant correlation between epistemological beliefs and personal beliefs in human biological evolution or human creation by God.

Table 9.4 displays the unstandardized regression coefficients (B) and intercept, the standardized regression coefficients (β), R^2, and adjusted R^2 after entry of all independent variables (IVs).

As seen in Table 9.4, the regression analyses revealed a similar pattern to the Pearson correlations. Using the personal beliefs in plant, animal, human evolution and human creation by God measures as dependent variables and the measures of epistemological beliefs (dimensions) as predictors in separate analyses revealed that there was a weak significant predictive relation between the epistemological beliefs dimension of source of knowledge and personal beliefs in plant evolution ($R^2 = 0.11$, Finc(1, 49) =6.09, $p = 0.02$) and animal evolution ($R^2 = 0.12$, Finc(1,49) = 6.68, $p = 0.01$).

The results of the regression analyses indicated no predictive relation between epistemological beliefs and personal beliefs in human evolution ($R^2 = 0.49$, Finc(5, 45) = 0.47, $p = 0.8$), and beliefs in Human Creation by God ($R^2 = 0.11$, Finc(5, 45) = 1.12, $p = 0.36$).

Table 9.3 Pearson correlations for all variables of the current study (N = 51)

Variable		1.	2.	3.	4.	5.	6.	7.	8.	9.
Epistemological beliefs										
1.	Certainty of knowledge	–								
2.	Simplicity of knowledge	0.08	–							
3.	Development of knowledge	0.30*	0.28*	–						
4.	Source of knowledge	0.30*	0.08	0.37**	–					
5.	Justification of knowledge	0.13	0.09	0.23	0.36**	–				
Personal beliefs in biological evolution										
6.	Beliefs in plant evolution	0.14	0.00	0.18	0.33*	0.00	–			
7.	Beliefs in animal evolution	0.16	0.30	0.21	0.35*	0.00	0.96***	–		
8.	Beliefs in human evolution	0.12	0.05	0.06	0.12	0.17	0.18	0.18	–	
9.	Beliefs in human creation by God	−0.9	0.08	−0.02	0.13	−0.10	−0.23	−0.23	−0.05	–

Note: ***p < .001, **p < .01, two-tailed; *p < .05, two-tailed

Table 9.4 Results of regression analyses for epistemological beliefs (dimensions) variables predicting personal beliefs in biological evolution (N = 51)

Predictor variables	Beliefs in plant biological evolution		Beliefs in animal biological evolution		Beliefs in human Biological evolution		Beliefs in human creation by God	
Epistemological dimensions	B(SE) β		B(SE) β		B(SE) β		B(SE) β	
Certainty of knowledge	0.05(0.21)	0.03	0.09(0.28)	0.05	0.17(0.36)	0.08	−0.31(0.36)	−0.13
Simplicity of knowledge	0.03(0.30)	0.02	0.10(0.30)	0.05	−0.18(0.34)	−0.08	0.38(0.39)	0.15
Development of knowledge	0.21(0.44)	0.08	0.21(0.40)	0.09	−0.16(0.50)	−0.04	−0.27(0.56)	0.08
Source of knowledge	0.61(0.29)	0.35*	0.64(0.29)	0.37*	0.26(0.35)	0.03	0.60(0.37)	0.28
Justification of knowledge	−0.30 (0.32)	−0.14	−0.31(0.33)	−0.19	0.29(0.37)	0.80	−0.48(0.42)	−0.18

Note: ***p < .001, **p < .01, two-tailed; *p < .05, two-tailed
Note: For personal beliefs in Plant Evolution: R = 0.37, R^2 = 0.13, Adjusted R^2 = 0.04
For personal beliefs in Animal Evolution: R = 0.39, R^2 = 0.16, Adjusted R^2 = 0.06
For personal beliefs in Human Evolution: R = 0.22, R^2 = 0.49, Adjusted R^2 = −0.06
For personal beliefs in Human Creation by God: R = 0.23, R^2 = 0.11, Adjusted R^2 = 0.01

The semi-structured interviews results indicated a similar pattern to that of the Pearson correlations and the regression analyses. All interviewed students expressed relatively sophisticated epistemological beliefs toward scientific theories and nature of knowledge and knowing, indicating that knowledge is tentative and evolving. For example, two students commented that "… scientific theories are reliable and well established, but sometimes they can change because of new evidence, new instruments or new interpretations …" Additionally, all five interviewees mentioned that it is necessary to form a personal opinion about what one reads/listens to. For example, three students commented that "… some scientists can make errors that harm people's health and the environment …".

All interviewed students mentioned that they believe in plant and animal biological evolution, but only two students mentioned that they believe in human evolution. The other students mentioned that God created human beings. For example, one student stated that "… animals and plants have evolved from other organisms, but the human being is God's creation. Another interviewed student used data from the Bible to explain the creation of Earth and Life and then expressed the idea that God guided evolution. One student mentioned that "…according our religion, humans were created by God, and I believe this…".

However, students who expressed highly sophisticated epistemological beliefs toward science were more likely to believe in human evolution compared to students with less strong / (OR weaker) and less sophisticated epistemological beliefs. Additionally, the results from the semi-structured interviews indicated that students' personal beliefs in human evolution were more related to their degree of religious commitment and not to their epistemological beliefs.

9.4 Discussion and Conclusions

The present research extends the current literature examining relationships between 12th grade students' epistemological beliefs toward science and their personal beliefs in plant evolution, animal evolution and human evolution, before biological evolution instruction. The findings indicate that students with relatively sophisticated epistemological beliefs, particularly beliefs about the source of knowledge, believe more in animal and plant evolution than students with less sophisticated epistemological beliefs. In other words, students who view science and scientific knowledge as a tentative and a dynamic process, and the result of the logical processing of facts and evidence with coherence, are also more likely to believe in plant and animal biological evolution. On the contrary, the more the students view science and scientific knowledge as fixed and authoritative, the more likely they are to not believe in evolutionary theory. On the other hand, our data showed no relationship between epistemological beliefs and beliefs in human evolution. Instead, our interviews findings showed high beliefs in human creation by God.

The finding that 12th grade students' epistemological source beliefs predicted their personal beliefs in plant and animal evolution, before biological evolution

instruction, constitutes a novel contribution of the present study. Furthermore, our interview results show that religious belief is an important influential factor in determining students' personal beliefs in human biological evolution. This finding is consistent with previous findings reported in the literature (Cavallo & McCall, 2008; Gould, 1997; Winslow et al., 2011; Woods & Scharmann, 2001). According to Gould (1997), although epistemologically, religion and science can be considered as non-overlapping magisteria, pedagogically these two magisteria could potentially overlap each other in a student's mind; thus feeding their opposition to biological evolution and promoting beliefs in human creation by God.

The finding that human beings are not automatically considered as animal organisms by the 12th grade students highlights the need for biology teachers to address students' misconception in order to foster their conceptual understanding of the biological evolution of all living organisms. Researchers of conceptual change have explored the impact of different factors on students' understanding of the process of conceptual understanding (Pintrich, 1999; Sinatra & Pintrich, 2003). They argue that affective constructs, epistemological beliefs and religious factors can be brought intentionally to bear on the process of conceptual change and learning (Pintrich, 1999; Reiss & Harms, 2019; Rosengren et al., 2012; Sinatra & Pintrich, 2003). This means that the way in which students understand the nature of knowledge and knowing, their religious beliefs and their personal views of the world may impact their conceptual change mechanism and learning about biological evolution.

Our research has important educational implications, showing that one goal of biology education should be to teach students to inquire about the world around them in an objective manner, taking into consideration that science and religion are distinct systems, and being aware that questioning what they know and think does not necessitate that they change their faith. Yet, biology teachers should address students' misconceptions about human biological evolution (among others) and foster students' epistemological beliefs and their familiarity with the methodological principles of scientific knowledge that – by their very nature – set the boundaries on what science can address.

Additionally, our research points to the need to invest in efforts to foster students' source epistemological beliefs. When students understand that knowledge is actively constructed by the person in interaction with others, and they view their current knowledge about the world as something that will change with new knowledge, perhaps they will become open to continued inquiry and questioning in every aspect of their lives.

In summary, the present study extends the current literature by examining relationships between epistemological beliefs toward science and personal beliefs in plant evolution, animal evolution and human evolution, before biological evolution instruction. Our results show that 12th grade students' epistemological beliefs predict their personal beliefs in plant evolution and animal evolution, but not in human evolution. Our findings suggest the need to design educational programs to support the development of students' epistemological beliefs toward science, supporting students: (a) to understand and be able to practice the processes of science, to experience the tentative and evolving nature of science, and to logically and thoughtfully

analyze scientific evidence, making their own logical arguments that justify their personal beliefs; (b) to understand how and why knowledge produced through science is different from their religious, social and cultural beliefs; (c) to understand the nature of knowledge and knowing and the methodological principles of scientific knowledge which may impact students' conceptual change mechanism and learning about the theory of biological evolution, with an emphasis on human evolution.

Inquiry-based teaching and learning (Shi et al., 2020), learning by using history of science (Matthews, 1994), dialogic argumentative activities (Iordanou & Constantinou, 2014) and reflective judgment through socioscientific issues (Zeidler et al., 2009) are some of the recommended didactical approaches to foster students' epistemological beliefs. However, the recommended didactical approaches are synergistic, build upon one another, and provide opportunities to foster students' epistemological beliefs (Baytelman et al., 2023).

There are some limitations to the current study that may provide impetus to further work in this area. The first limitation concerns the small size of our sample, consisting of 51 students. The second limitation concerns the impact of the school unit and the residence of the participants. All of the participants came from the same school unit and from the same region: They shared a homogeneous middle-class social background, and the same language and religion. The third limitation concerns the small size of semi-structured interviews, consisting of five interviews. The last limitation concerns the Pearson coefficients, as well as the R^2 in the multiple regression analyses in the present study, which were low. Further research is required to replicate these findings, which will be of interest to researchers, educators and biology teachers in the field.

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