

## Item Description

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

*Note: Parentheticals are not part of the questionnaire.*

*[This question aims to assess respondents' views regarding science as a discipline to address questions about the natural world, the role of science in providing explanations for natural phenomena, and the role that empirical evidence plays in science that separates science from other "ways of knowing." Responses to this question often reveal a common misconception regarding the use of the "Scientific Method" as an objective process by which the knowledge is discovered. Such a view is often presented as an explanation for how science differs from other disciplines of inquiry.]*

2. What is an experiment?
3. Does the development of scientific knowledge **require** experiments?
  - If yes, explain why. Give an example to defend your position.
  - If no, explain why. Give an example to defend your position.

*[Questions #2 and #3 are used in combination to assess respondents' views of investigative processes in science. Question #3 elicits responses regarding the existence of multiple methods of investigation (such as experimentation involving controlled variables, correlational studies, and descriptive investigations) that do not all follow the traditional "Scientific Method" or set of pre-established logical steps requiring a testable hypothesis. Responses to Question #2 clarify respondents' ideas of "experiment," as often this term is defined differently. Question #3 is then interpreted in relation to the provided description of "experiment." Question #3 also may elicit views of subjectivity and creativity in science.]*

4. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence, or types of evidence, **do you think** scientists used to determine what an atom looks like?

*[This question refers respondents to a concept from the physical sciences to assess their understandings of the role of human inference and creativity in developing scientific explanations and models based on available data, and the notion that scientific models are not copies of reality.]*

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

*[This question assesses respondents' views of the development of and relationship between scientific theories and laws. The common misconception of the existence of a hierarchical relationship is often revealed. This misconception is presented by the explanation of a progression from scientific theory to law with the accumulation of more and more evidence until the theory has been "proven true" at which time it becomes a law. Views regarding distinctions between observation and inference are also commonly elicited. Additional ideas are often expressed by respondents as they attempt to describe the differences between scientific theories and laws.]*

6. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?

- If you believe that scientific theories do not change, explain why. Defend your answer with examples.
- If you believe that scientific theories do change:
  - (a) Explain why theories change?
  - (b) Explain why we bother to learn scientific theories. Defend your answer with examples.

*[This question assesses respondents' understanding of the tentative nature of scientific theories and reasons why science is tentative. Respondents often attribute change solely to the accumulation of new observations or data and/or the development of new technologies, and they do not consider change that results from reinterpretation of existing data from a different perspective. Views of the theory-laden nature of scientific investigations, the notion that the prevailing theories of the time impact the direction, conduct, and interpretation of scientific investigations, are assessed through the explanation of the role of theories in science. Additionally, responses often indicate views of the role of subjectivity, creativity, inference, and the sociocultural embeddedness of the scientific endeavor, as well as the interdependent nature of these aspects.]*

7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence **do you think** scientists used to determine what a species is?

*[This question refers respondents to a concept from the biological sciences to assess their understanding of the role of human inference, creativity, and subjectivity in science. Desired responses describe the idea that "species" is defined by scientists to explain observed and inferred relationships, and that definitions as well as concepts in science are created by scientists to be useful for their endeavors. Additionally, this question elicits responses concerning the role of models in science and that scientific models are not copies of reality.]*

8. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
- If yes, then at which stages of the investigations do you believe that scientists use their imagination and creativity: planning and design; data collection; after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
  - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

*[This question assesses respondents' views of the role of human creativity and imagination in science, and the phases of scientific investigations at which respondents believe these aspects play a role. Often creativity is described relative to design only, and usually in regard to resourcefulness necessary to set up and conduct investigations (such as design of new trapping methods in the wild). Respondents are less likely to recognize the role of creativity in question development, data analysis, and interpretation. Ideas of "discovery" versus "created patterns" are elicited.]*

9. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these **different conclusions** possible if scientists in both groups have access to and **use the same set of data** to derive their conclusions?

*[This question assesses respondents' understandings of reasons for controversy in science when scientists use the same available data. Ideas of subjectivity, inference, creativity, social and cultural influences, and tentativeness are often elicited. The question aims to assess respondents' beliefs about what influences data interpretation including personal preferences and bias (personal subjectivity) to differing theoretical commitments and impacts of social and cultural values.]*

10. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.
- If you believe that science reflects social and cultural values, explain why and how. Defend your answer with examples.
  - If you believe that science is universal, explain why and how. Defend your answer with examples.

*[This question assesses respondents' views of the impact of social and cultural values and expectations on the scientific endeavor. Naïve views are often indicated by responses describing science as "value free" and stating that different cultures and belief systems do not impact the way science is conducted or the interpretation or use of scientific knowledge. Views of connections between sociocultural influences on science and subjectivity, creativity, inference, and tentativeness are often elicited.]*

## VNOS Interview Protocol

Participants are provided with their VNOS responses to read and review.

1. Could you read your response to question # 1 (2-10) and explain and elaborate on your response?
2. What did you mean by [response, written or verbal]?
3. Could you give an example of what you meant by [response, written or verbal]?
4. How does your response on # X relate to what you said on # Y?
5. Have your views changed since you wrote your response? If so, how?

NOS aspects and descriptions that serve as a basis for evaluation of VNOS responses

Aspect	Description
Tentativeness	Scientific knowledge is subject to change with new observations and with the reinterpretations of existing observations. All other aspects of NOS provide rationale for the tentativeness of scientific knowledge.
Empirical basis	Scientific knowledge is based on and/or derived from observations of the natural world.
Subjectivity	Science is influenced and driven by the presently accepted scientific theories and laws. The development of questions, investigations, and interpretations of data are filtered through the lens of current theory. This is an unavoidable subjectivity that allows science to progress and remain consistent, yet also contributes to change in science when previous evidence is examined from the perspective of new knowledge. Personal subjectivity is also unavoidable. Personal values, agendas, and prior experiences dictate what and how scientists conduct their work.
Creativity	Scientific knowledge is created from human imaginations and logical reasoning. This creation is based on observations and inferences of the natural world.
Social/cultural embeddedness	Science is a human endeavor and, as such, is influenced by the society and culture in which it is practiced. The values and expectations of the culture determine what and how science is conducted, interpreted, and accepted.
Observations and inferences	Science is based on both observations and inferences. Observations are gathered through human senses or extensions of those senses. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.
Theories and laws	Theories and laws are different kinds of scientific knowledge. Laws describe relationships, observed or perceived, of phenomena in nature. Theories are inferred explanations for natural phenomena and mechanisms for relationships among natural phenomena. Hypotheses in science may lead to either theories or laws with the accumulation of substantial supporting evidence and acceptance in the scientific community. Theories and laws do not progress into one and another, in the hierarchical sense, for they are distinctly and functionally different types of knowledge.