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Promoting Public Understanding in the Science of Geology

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Abstract: Geology is perhaps the most fascinating of the natural sciences, due to its all-encompassing nature. Virtually all human activities that occur on planet Earth—including agriculture, energy and mineral resource exploration and extraction; environmental and public policy on natural resources management and protection; land use planning; infrastructure development; and ecological tourism—all depend on various aspects of geology and its sub-disciplines. Due to the importance of geology in the daily lives of human beings, it is imperative that all persons develop at least a basic understanding of the science. In this paper, the current efforts for promoting public understanding in geology will be examined, with offerings of alternatives and supplements to these efforts. Information from the science education sub-disciplines of HPS (history, philosophy and sociology) of science, and informal/free-choice learning will be woven into the framework of the geology-public understanding idea.

Key words: Environmental and public policy, geology, history, philosophy and sociology of science, informal/free-choice learning, public understanding of science.

1. Introduction

Studies of public understanding of science that focus upon geology are limited, in terms of the overall body of research on the subject. In short, such studies are virtually non-existent, both from the perspectives of science education and the geosciences. Geology is an inseparable part of the natural and human world, in terms of materials, energy, and environmental resources. As such, there is a need for studies to emphasize both the science's importance overall, and, to determine methods for improving the public's understanding of the science. Therefore, this paper serves as a means of augmenting this limited body of research on the public understanding of geology.

The following method will be used in this study. First, the science of geology will be examined, as an eclectic natural science with a unique method of inquiry and, strong public education and environmental/public policy connections. Second, some details about public understanding of science will be highlighted, in terms of relating them to the science of geology. The role of informal and free-choice learning will also be discussed in this section. Third, the science of geology will be examined further, through each component of the HPS (history, philosophy and sociology) of science lens. Fourth, the current methods for conveying geological information to the public will be evaluated. Fifth, there will be a discussion of additional venues for promoting public understanding in geology, along with their advantages and disadvantages. Sixth, concluding remarks will be provided about future directions that could be taken to improve the public understanding of geology.

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2. The Science of Geology

2.1 Geology: Defined and Eclectic

According to Coates [1], geology is defined as "the study of the Earth and its resources". However, this definition does not fully account for geology's most amazing attribute: its status as perhaps the most eclectic of the sciences. Geology has a number of sub-disciplines that incorporate characteristics of the other natural sciences of biology, chemistry, and physics.

Geology relates to biology through paleontology, the study of fossils. The Earth's fossil record serves as a vast reminder of what types of plant and animal life form inhabited the planet, and also gives clues as to how these life forms adapted and changed over time, as well as how they connect with the animal and plant life found on planet Earth today. New opportunities for learning about ancient plants and animals arise periodically, with the discovery of previously unknown species in the fossil record.

Geology relates to chemistry through geochemistry, the study of how the Earth's natural elements interact with each other; these interactions are responsible for the formation of metallic and non-metallic mineral deposits, fossil and nuclear fuels, and various types of surface and groundwater resources. Mankind has used these mineral, energy, and water resources for several millennia, and the science of geochemistry has become quite instrumental in locating new sources for these materials.

Geology relates to physics through geophysics, the study of earth movements. This branch of the science has proven most helpful to mankind, as it is used to delineate areas that are prone to natural disasters or environmental hazards (e.g., landslides, rock falls, sinkholes, volcanic eruptions, earthquakes). Because geology is such an eclectic science, a better definition for the science is "the study of planet Earth, its resources, its past activities and inhabitants, and its future where its present inhabitants are concerned" (Snowden, 2002) [2]. Fig. 1 provides a summary of the aforementioned examples of how the science of geology connects to the sciences of biology, chemistry and physics.

2.2 Geology and Scientific Inquiry

Scientific inquiry in geology is unique in that it deals with objects that have natural-based histories (e.g., rock formations, fossils, mineral deposits). According to Ault (1998) [3], the histories in geological-based objects create a demand for concepts that contain at least some ambiguity, allowing them to be compared and contrasted with similar objects. The ambiguity in question here involves differences in the overall interpretation of geologic phenomena, which can vary greatly. This same ambiguity can also be present in how geological concepts are defined (these are likewise, highly variable). In any case, ambiguity is a necessary component to all sciences, as it plays a role in generating debate about any scientific phenomena [3].

With geology, ambiguity can have extensive consequences in matters where human issues are involved (e.g., varying interpretations of groundwater availability, occurrence and flow can determine whether or not a groundwater resource is developed for a community). In any case, ambiguity in geology should

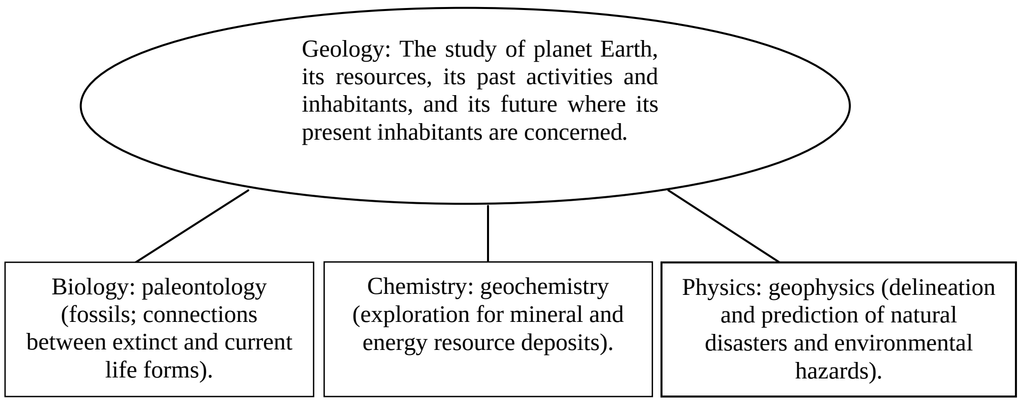

Fig. 1 Examples of how geology connects to biology, chemistry and physics.

be confronted with caution, because some studies in this particular science can impact mankind directly (e.g., predicting natural disasters and their impacts), and such studies should ideally be conducted by individuals from varying perspectives who can work together and come to a consensus on geological interpretations of different subjects.

2.3 Geology, Public Education, and Public/Environmental Policy

Due to its all-encompassing nature, it should come as no surprise that geology has a major role in the development of environmental and public policy. This is because human activities on planet Earth involve the use of land and related natural resources found both above the Earth's crust (e.g., trees for lumber) and below the Earth's crust (e.g., coal for energy production). In order to ensure that these resources are properly maintained and used, public policy is developed, usually in the form of guidelines, rules, and regulations.

Much of the public policy related to geology phases into environmental policy (e.g., water resources protection, waste disposal, and land use/management). Government agencies at the federal (e.g., US Department of the Interior) and state (e.g., PA Department of Conservation and Natural Resources) levels in the United States and abroad have been set up to maintain all natural resources through the use of rules and regulations that persons must follow. Additionally, they have set up organizations that deal specifically with the management of geological resources (e.g., US Geological Survey, PA Geological Survey).

The relationship between geology and public/environmental policy will remain strong. This is because mankind continues to exercise considerable influence on the natural environment, as issues related to land, waste and water management continue to persist. Current issues of addressing the global warming dilemma through decreasing the use of fossil fuels, and striving for better overall management of land, water, mineral, and energy resources, all add to the need to keep geology and public/environmental policy linked [4].

Along the same lines, geology also carries connections to public education. There are numerous earth science educational pamphlets and booklets produced by both public and private entities (e.g., PA Geologic Survey, AGI (American Geological Institute)), as well as the basic earth science textbooks and user guides for those who wish to learn about the geological sciences, either in the classroom or on their own. Additionally, geology makes its way into the lives of mankind through magazines (e.g., National Geographic), newspaper articles, and television specials on various networks (e.g., TLC (the learning channel), the PBS (public broadcasting system)). It is this aspect of geology that needs additional attention, as the science is not taught all that much at most levels of schooling (except for the college and university levels and, some secondary school levels). Since the science is essentially a part of everyday life, and it is virtually impossible for society to exist without it, it is imperative that geology be understood by all sectors of the public, whether individuals are students, homemakers, citizens, academics, business and industrial types, government persons, or from civic and environmental organizations.

3. Geology and Public Understanding of Science

3.1 Public Understanding in Science—An Overview

In recent years, there has been a movement to create a society that is scientifically literate, per in- and out-of-classroom activities. For this goal to be achieved, it is necessary for educators to understand how the scientific community interacts with citizens. Researchers have approached this idea from many different angles. For example, Ziman [5] came up with three basic questions on scientific community-citizen interactions while examining the idea of the public understanding of science: (1) what do people say about science? (i.e., comparing the thoughts about scientific disciplines among practicing scientists in academia, business and industry, and government, along with the general public's perceptions of science); (2) how do people use science? (i.e., evaluating the avenues where various sectors of the public engage in studying and/or applying science); and (3) how is scientific knowledge received? (i.e., examination of methods used to convey scientific knowledge and, the reaction of those receiving this knowledge) [5]. Citizens are interested in how scientists come up with the answers that they do when practicing science. As such, there is a need for scientists to share their practicing methodologies by conveying information about these methodologies to citizens, and in a manner that citizens will be able to understand.

From another perspective, Jenkins [6] looked at the public understanding of science, and linked this idea with citizenship and school science. He came up with the conclusion that "everyday thinking is more complex and less well understood than scientific thinking, and is well adapted to decision-making in an everyday world which, unlike science itself, is marked by uncertainty, contingency, and adaptation to a wide range of uncontrolled factors" [6]. He defines the term "citizen science" (science that relates to the concerns and activities of citizens as they go about their everyday business; this is simply the body of practical knowledge that all citizens obtain through life experiences—the scientific knowledge that is interconnected with this practical body of citizen knowledge usually relates to a social or institutional issue (e.g., locating a landfill for citizens to dispose of solid wastes)), and mentions the salient questions that citizens are likely to ask about science and scientific information: (1) from whom does the scientific knowledge come? (i.e., what person or persons are practicing science and generating information?); (2) from where does the scientific knowledge come? (i.e., where can the persons involved in scientific practices be found?); and (3) from what organization or source does the scientific knowledge come? (i.e., who are the persons practicing science working for and where are they getting their information that they are working with?) [6]. In short, there is a need for those practicing science to: (1) respect citizens' general thought processes; (2) understand the questions that citizens have about science, and be prepared to address these questions; and (3) connect the sciences they practice to matters that affect citizens on a daily basis.

Still another related perspective is provided by Tytler [7], who looked at evidence on public understanding of science, and related these to science education. His studies dealt with literature that focused upon the interactions between science and the public, and how information is conveyed to the non-scientific community. His initial conclusions from this literature review were that "the interaction between science and the public cannot be simply represented as a unidirectional translation process, but one that inevitably involves a negotiation between different perspectives that encompass a complex array of knowledge and values." "Additionally, judgments about evidence are often central to interactions between science and the public, and with school science, there is a disconnection between the explanatory science of the school curriculum and the participatory science utilized by the public when confronted with issues of real concern" [7]. In short, there is a need for connecting scientific knowledge (both at the professional and schooling levels) to larger issues that affect citizens, along with a need to improve how scientific information is conveyed from scientists to citizens.

All three preceding perspectives do point to several commonalities: (1) public perceptions of science need to be taken into account more carefully when scientific information is conveyed to non-scientists; (2) better connections are needed between scientific knowledge and the daily lives of citizens when this knowledge is conveyed to citizens, and the methods that scientists use should be part of these connections; and (3) an overall connection between science and real world problems needs to be conveyed to citizens.

All of these ideas about public understanding of science could play a role the goal of achieving scientific literacy for all. Literacy in the basics of geology should definitely be part of the overall scientific literacy goal. This is because geology is a science that affects virtually all aspects of human. As such, knowledge from this science is vital for all mankind, and understanding the many facets of this science is even more so.

3.2 The Role of Informal/Free-Choice Learning

According to Falk [8], informal/free-choice learning is the type of learning that individuals do on their own (outside of classroom settings), due to interest in a particular subject or set of subjects. Informal/free-choice learning plays a significant role in the public understanding of science, due to the wide range of venues available. The informal/free-choice learning sector can include museums, television, radio, the Internet, magazines, books, and community organizations. Unfortunately, informal/free-choice learning is receives only 1% of all government educational expenditures, even though the government supports free-choice learning arenas such as libraries, national parks, public television and radio, and museums [8].

Aspects of the sciences may also be studied in the informal/free-choice learning arena. Since most persons have access to at least one avenue for informal/free-choice learning, opportunities for persons to find out about scientific concepts are quite extensive. Many persons find out about scientific phenomena through newspapers, magazines, television programs, science and natural history museums visits, books (technical, non-technical, and self-teaching guides), and the Internet. Persons use any one or more of these avenues to develop their own understanding of various scientific phenomena.

With all of these aforementioned opportunities available for persons to learn and understand science, the reality is that the free-choice learning sector can no longer afford to be ignored by government or the science education community, especially. With geology, interested persons may engage in free-choice learning about the science through the same avenues mentioned above. There continue to be newspaper articles that showcase mineral or energy deposits or natural disasters). These same subjects are often covered in scientific magazines (e.g., Scientific American), television shows (e.g., Nature), self-learning guides (e.g., On the Rocks—Earth Science for Everyone [9]) and educational guides produced by government or private agencies (e.g., PA Geologic Survey Earth Science Education Series Booklets). All of these venues play a role in helping interested persons to understand geology as a science. However, to complete the picture, consideration should be given to the HPS of science and how its elements interconnect with those of the public understanding of geology. Fig. 2 provides a schematic for this relationship, and all elements in this figure are discussed in the following section.

4. Geology and the HPS of Science

4.1 Premise of Linking the History of Science and Geology

According to Matthews [10], the history of science looks at the development of scientific concepts over time, through the examination of the individual thinking on scientific phenomena. Knowledge is developed from this thinking, and from here, various theories may come to light. History of science also looks at the lives of individual scientists and how they worked to advance the particular scientific discipline they were involved in; this process helps all parties to understand how scientific ideas change over time, along with the very nature of science—an interactive, interdisciplinary, and interdependent entity [10].

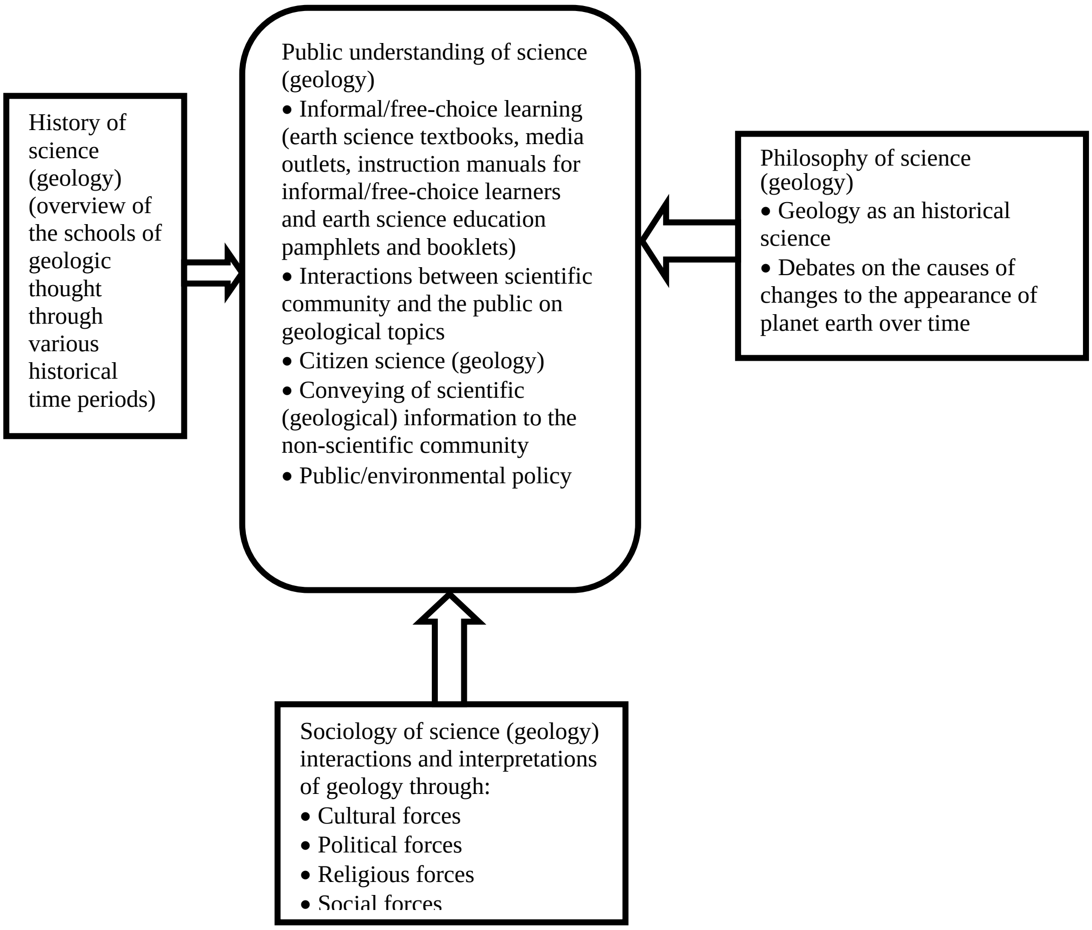

Fig. 2 Public understanding of science (geology): interconnections among elements within its own discipline and from HPS (history, philosophy and sociology) of science.

4.2 The Abridged History of Geology

Geology has a rich variety of perspectives that have developed throughout its history. Two competing perspectives regarding planet Earth's origins have dominated. The first one is "uniformitarianism" which is based on the concepts of uniformity and continuity. This school believed that the geological processes that occur on planet Earth today have always acted at a steady rate throughout the past, and that the present appearance of the Earth was the result of these gradual processes. The other school is "catastrophism", or the belief that changes to the Earth's features had come through sudden catastrophes (e.g., flooding, earthquakes). An example of an early catastrophist was the philosopher Plato, who believed that planet Earth's history was marked by natural disasters. On the other hand, the philosopher Aristotle (Plato's pupil) was an uniformitarian who believed that the Earth is everlasting and that land decays and renews itself in a smooth and unending cycle. Up to the 1200s, natural disasters strongly influenced the thinking of geologists, and catastrophism appeared to have the upper hand, as it seemed to mesh with biblical accounts of floods and other disasters [4].

At around the 1500s, mining took hold as a geological interest, and this led to the publication of the first handbook of minerals and economic geology, entitled "De Re Metallica"; this handbook was authored by the German scholar Georg Bauer who was also known as "Agricola", or the farmer. At the same time, the artist/scientist Leonardo da Vinci became one of the first persons to recognize fossils, and classified them as traces of once-living organisms. Another catastrophist in geology emerged during the 1600s. Niels Stensen (known as Steno) accepted the Bible's account of Earth's creation and believed that fossils were relics of plants and animals killed during Noah's flood. He also developed the Law of Superposition which means that the oldest rock layers are at the bottom, and the youngest rock layers are at the top. This principle is still used by geologists today [11].

On the other hand, Robert Hooke focused upon the mechanical and physical processes that helped to shape the Earth's features. His vision of geological history accounted for both slow, uniformitarian processes and sudden catastrophes. He was among the first to suggest that species become extinct due to changes in their environment. This was an early form of evolution. Additionally, James Hutton, who is often referred to as the "father of modern geology", envisioned the history of planet Earth as an unending cycle of processes. He recognized that erosion wears away rock and soil, carrying them down to the seas, where they harden into new rock and landmasses. He also introduced the idea that geological time was much longer than originally believed (the prevailing opinion was that the Earth was only a few thousand years old). In short, Hutton found that planet Earth "has no vestige of a beginning, or no prospect of an end." [11].

Later, during the 1700s and 1800s, other schools of geological thought were developed. These were the Neptunists, who followed the German geologist Alfred Wegner, who developed the pre-plate tectonics theory of Continental Drift. Neptunists believed that planet Earth had at one time been covered by water, thanks to the biblical flood—his qualified as a catastrophist belief. On the other hand, there were the Plutonists who believed that the Earth's crust had been shaped by extreme heat from within the planet, as opposed to water—this group supported Hutton and uniformitarianism, and their leading spokesperson, John Playfair, was the first to publicize Hutton's work. Two other catastrophists from France, George Cuvier and Alexandre Bronginart, suggested that sudden geological changes had caused the large-scale extinction of species; these two individuals were instrumental in developing the geological science of paleontology, the study of fossils [11].

The belief in biblical flooding and its influence on planet Earth was maintained by Adam Sedgewick, who believed that this flooding event was responsible for the appearance of the Earth's surface. On the other hand, the Swiss engineer Jean Louis Rodolphe Agassiz proved that the Earth's surface features had been caused by movements of glaciers during past ice ages. Additionally, William Smith, an English surveyor and mining engineer, developed a practical new way to create maps: he identified strata (layers) of rock by the fossils they contained. This work led to the geological science of stratigraphy, or the study of rock layers [4].

The developments in geology that are mentioned above relate to studies in Europe. However, geology did gain a foothold in the United States as well, especially during the 1800s and continuing to the present day. For example, William McClure developed the first geological map of the United States, while Benjamin Sillman founded "The American Journal of Science", the oldest scientific journal in the United States. The geology of the western United States was mapped by Clarence Rivers King, John Wesley Powell, and Grove Karl Gilbert. This information led to the publication of numerous reports containing new geological information, and was instrumental in adding to the newly-growing the national park system [11].

During this same period, the time frame of planet Earth was now looked at as being longer than just a few thousand years, and several geologists and related scientists helped to convey this idea further. For example, Charles Lyell of England calculated that about 240 million years had passed since the appearance of complex life forms on planet Earth. He published the first comprehensive work specifically for geology, the three-volume "Principles of Geology". Lyell's work was continued by Charles Darwin who developed the modern theory of evolution, with the premise that species evolved over long periods of time. Although this theory was temporarily side-tracked by William Thompson (also known as Lord Kelvin) who believed that the Earth was only about 100 million years old, and based this argument upon the idea that the rate at which the Earth cooled from its original molten state. However, the discovery of radioactive minerals opened the door to radiometric dating, allowing modern geologists to estimate the age of planet Earth at about 4.55 billion years [11].

Other geologists involved in developing the science during the 1900s to the present day include the Swiss geologist Eduard Suess who developed the theory that the main forces behind geological changes were the cooling and shrinking of the planet. These activities produce vertical movements in the planet's crust. Alfred Wegner's theory of continental drift was still in effect at this time as he looked at the Earth's continents as having large-scale horizontal movements. The main thrust of his argument was the belief that the Earth's continents were once one large landmass (Pangea) that broke apart and drifted to their present positions. However, another geologist, Harry Hess, argued in the 1960s that molten magma welling up from cracks in the sea floor spread and pushed the continents apart. The cracks formed then divided the Earth's surface into several major and minor plates. This gave rise to the modern theory of plate tectonics, which is the study of the motion and interaction of the Earth's landmasses; this theory is widely believed among geologists at the present time [12].

Today, geologists are still at odds with how various features of planet Earth came to develop, and this provides some interesting discussions during meetings and related gatherings of geologists.

4.3 The History of Science-Public Understanding Connection

As described in the above historical overview, geology has come a long way as a scientific discipline. Throughout its development, there have been numerous, conflicting ideas about how the science works, and how the features of planet Earth came to appear as they do today. These same ideas can play a role in helping the public to understand just how geology has been, and continues to be, important to society. The idea here is for those who would teach about geological concepts to the public to focus more upon the individual geological scientists and their contributions to society relevant to the time period studied. For example, the work of James Hutton could be examined as the initial point for geology as a science, since the impact of the science was relatively misunderstood until that time—mainly due to the religious and cultural influences upon practicing scientists.

In the modern day, the work of geologists across the globe could be examined for what it might mean to society at large (e.g., locating evidence of global warming patterns). The same history of science concept could be used here by looking at past practices (e.g., the publication of the first minerals textbook), and comparing the societal impacts to similar practices of geologists today (e.g., discoveries of minerals that were initially unknown). In any case, it is the best way to incorporate history of science into the public understanding of geology by focusing upon the lives and work of geologists through time and connecting their practices to societal impacts.

4.4 The Philosophy of Science—Geology

This philosophy component of HPS looks at how scientists understand the world, and examines science in the context of philosophical ideas. Here, prevailing cultural views affect the direction of science. Various terms (e.g., "law", "theory", "model", "explanation", "cause", "truth", "knowledge", "observation", "time", "space", "evidence", "field", "species" and "idealization") are common to both philosophy and science; their use in classrooms helps in answering questions on terminologies (what one knows) and meaning (how one knows) (Craig, 1998) [13].

Throughout much of its history, the major philosophical issue for geology was how it was analyzed as being an historical science. Initially geologists, as opposed to philosophers, did much of the thinking on this aspect of geology. The first known philosophical reference specifically to geology was during the 19th century when the English philosopher-scientist William Whewell dubbed Lyell's "Principles of Geology" as an uniformitarian analysis in the Quarterly Review of Philosophy. In his "Principles of Geology" manuscript, Lyell had suggested: (1) that the laws of nature had not changed over time—law uniformitarianism; (2) that the kinds of causes operating in nature had not changed over time—degree uniformitarianism; and (3) that the intensity of those causes had not changed over time—degree uniformitarianism. Law uniformitarianism was generally agreed upon by geologists, as they, like most other persons, believed that the laws of nature were constant in and of themselves [13].

However, law uniformitarianism and degree uniformitarianism were controversial entities, since geologists throughout history had argued that the causes for Earth's appearance were changeable in both kind and intensity. The basis for this controversy could be traced to the principle of "vera causa" (true cause) that was brought forth in Sir Isaac Newton's "Principia mathematica" specifically, the section on Rules of Reasoning. This same principle was clarified further in Thomas Reid's "Essays on the Intellectual Powers of Man", where: (1) there must be direct, observational evidence that causes of some kind do exist; and (2) there must be evidence that the causes were sufficient to produce the purported effects [13].

Since it has never been possible for geologists to actually have observed events that went on in the past, observing the causes for the Earth's appearance that occur today (e.g. earthquakes, volcanic activity, seafloor spreading, floods, erosion) serve as clues to what had occurred in the past. Additionally, written records of geological activities that had occurred through time could be accessed, where available (this accounts for anything that was not observed by the present observer). In this fashion, law and degree uniformitarianism could be looked at as a means of extending the vera causa principle to situations in which cause and effect are vastly separated in time. However, the opposing philosophy of catastrophism was still embraced by some geologists at the time.

The most recent (1960s) major theoretical change to the science of geology was the plate tectonics theory, which helped to shift the philosophical focus of geology away from determining whether the science is historical, and towards determining actual causes for planet Earth's appearance. The image of geology developed as a result of the plate tectonics theory was one molded in logical positivism: the science progresses through confrontation of hypotheses and evidence, so that gradually and cumulatively, a body of well-founded conclusions can be established [13]. Additionally, the plate tectonics theory has been called a revolutionary change in geology, and some of the geologists involved in this "revolution" drew from Kuhn's "Structure of Scientific Revolutions" (1996, 3rd ed.) [14] stating that the plate tectonics theory qualified as a revolutionary change in the science of geology. While most philosophers of science do not necessarily characterize the plate tectonics theory as a Kuhnian revolution for science, they agree with the geologists that such a theoretical change can pose future challenges to the logical positivists. In the scientific realm, this simply takes the form of continually competing philosophies about various geological subjects.

4.5 The Philosophy of Science-Public Understanding Connection

Whenever a science is debated on philosophical grounds, many sectors of the public will hear about it, and weigh in with their own ideas and beliefs. This has happened with geology with the theory of evolution. Many communities, even today, do not fully believe in this theory, and instead take their interpretations of Earth history from the Bible. Situations like this can create breeding ground for dialogue on public understanding of geology and its proper place in society. In order for this to happen, the philosophical perspectives of all interested parties must be presented, exchanged, analyzed, and ultimately refined. This is the same pattern that most philosophies about geology (i.e., catastrophism vs. uniformitarianism, Plutonism vs. Neptunism) came into being, and changed through time.

Openness on the part of all parties will be paramount; one major drawback on any philosophy is that those developing or involved in certain schools of thought sometimes tend to hold on to their beliefs, even after being exposed to alternate theories. The "truth" in a philosophy of a science, geology especially, will only be accepted if the proper steps are taken to educate all parties on what evidence is available (past and present) to show why planet Earth appears as it does, by what means this appearance occurred, and the intensity of those means causing the appearance. The education process will have to be multi-directional, with an initial presentation of ideas shared by all parties involved.

4.6 Sociology of Science and Geology

According to Cunningham and Helms [15], the sociology of science aspect of the HPS of science describes how science is practiced and constructed by society, with a focus upon the reciprocal interactions and influences between science and social forces (political, economic, cultural and religious). Through studies of the human relationships, beliefs, and values that pervade science, sociological insights tend to challenge stereotypes (e.g., the image of the scientist as a man in a lab coat) and erode the unwarranted status and permanence of science (e.g., portraying scientists as "heroes"), to bring the human and societal components into better perspective. In short, some of the descriptions of science that sociology generates may not match with what appears in science textbooks or classrooms, along with how the general public views science. Studies in the sociology of science can be micro-sociological (viewing how science is constructed and, how social and personal concerns and beliefs affect scientific decisions in the work place) or macro-sociological (looking at the interaction of science with society, per the influences of social, political, cultural, religious, and economic factors, and their impacts upon science practices) [15].

With geology, sociology of science perhaps has the most pivotal role among the HPS of science components, particularly in the macro-sociological category. Geology connects to the natural environment, which all human beings on planet Earth depend upon (to varying degrees) to survive. How any person or group of persons looks at geology will have an impact upon any audience these persons convey their information to. For example, if one group of geologists from a corporation has the perspective of the same geology that differs from that of a group of geologists from a government agency, there will be public outcry—most likely in hopes that the government geologists' perspective prevails. Here, the general public's views of the scientists would be as both "heartless" (corporate) and "sympathetic" (government).

In the public realm, especially with politics and economics, geology has a love-hate relationship. For example, some local governments, even though studies of the geology of a specific area may call for drilling wells to better delineate a groundwater problem, may opt to forgo drilling wells, due to a lack of money, political pressure (or both), and delineate the groundwater problem in a less expensive and often incomplete fashion. On the other hand, for the same political and economic reasons, geologic studies are looked at as boons to natural resource exploration and development, when it comes to locating mineral and energy fuels, metals, and non-metals. In all cases however, when it comes to sciences, geology probably has the most visibility for the sociology of science.

4.7 The Sociology of Science-Public Understanding Connection

In the sociology of science realm, public understanding of science has a major niche, especially with geology. Since geology interacts with many aspects of the environment that matter to society (water, energy, etc.) and, this science, too, is subject to variable interpretations from both those who practice the science and those who receive information from it, developing methods for public understanding of geology is vital to the future of both the science and humanity. Initially, any persons practicing geology should first meet with each other and debate why they hold the views that they do about the science; in some cases, compromises may be reached. From here, these same scientists should then meet with various sectors of the general public and get an idea of what these individuals think of the science of geology, from all perspectives within the sociological realm (political, economic, cultural, religious). At this point, ideas about geology can be shared on a larger scale, and possibly modified to fit the perspectives of all participants, while maintaining the premise of the original geological ideas.

5. Methods of Conveying Geological Information to the General Public

5.1 Earth Science and Geology Textbooks

Textbooks about the earth sciences, geology included, are used in academia, at all levels of traditional schooling. While these textbooks tend to focus on a particular branch of geology or earth science (e.g., astronomy, geography, mineralogy, structural geology, meteorology, oceanography), many of these same textbooks are now written with practical applications in mind (i.e., careers in the earth sciences and geology are highlighted). However, it should be noted that as an individual strives to learn about geology or earth science through academic avenues, the subject matter for subsequent courses in the science becomes more advanced. In this case, the more advanced the sub-discipline within geology or earth science becomes, the more specialized/sophisticated the textbook material becomes—this could reduce the scope of the audience intended for the textbooks. Therefore, any person who wishes to learn more about geology or earth science should plan ahead to determine just how keen his/her interest is in the subject, and select the appropriate geology or earth science courses to address this interest.

5.2 Media Outlets

Quite often, the science of geology makes its way into various media outlets. In the newspapers, there are often stories about geologic events (e.g., new fossil discoveries, natural disasters). Television also highlights geological events, through both public programs such as "Nova" and "Nature" and, through a variety of programs run on cable television stations such as the DSC (Discovery Channel) Magazines such as Scientific American, and E– the Environmental Magazine, often cover geological matters concerning the delineation and conservation of natural resources, along with geological natural hazards and how to best plan for these events.

5.3 Earth Science Education Pamphlets and Booklets

There are also educational publications on geological subjects that are published by government agencies. The best examples of these are the Earth Science Educational Series Booklets from the PA Geologic Survey, and similar pamphlets and booklets produced by the US Geological Survey. Other documents on geological subjects are sometimes produced by non-profit organizations (e.g., the League of Women Voters—groundwater resource documents), and the private sector (e.g., WMX (Waste Management, Inc), publications on geology and landfills). Additionally, most interested parties can access the

Internet to find out more about geological subjects, either for casual learning, or to complete a project of importance. In any case, all of the aforementioned media outlets can be used by a wide range of audiences in the general public, depending upon their collective levels of interest.

5.4 Instruction Manuals for the Informal/Free-Choice Learner

In some cases, persons may wish to learn about geology for their own edification and, outside of the classroom. For such persons who wish to understand geological concepts, there are instruction manuals available about geology (e.g., Murck's "Geology—A Self-Teaching Guide" [16]). These documents are written in the simplest terms, so that persons who may not have an idea about what geology involves will be able to understand. The geology instruction manuals contain baseline information about various topics (e.g., rocks, minerals, fossils, hazards), along with aspects of different branches of geology (e.g., petrology, sedimentology, stratigraphy), and they include highlighted terms and sample questions that are designed to work together, thus guiding the learner along. These documents can also be used by a wide range of audiences, any of which may work at their own pace; they are particularly for learners who truly want to find out more about the concepts of geology and/or earth science.

6. Venues for Improving the Understanding of Geology for the Public

On the whole, there is an extremely keen interest among all sectors of the public for learning more about geological concepts. As such, it is necessary for geological and earth science educators at all levels of schooling and learning to develop a variety of venues to meet this interest. Snowden (2001, 2002 and 2003) [17-19] originally presented these venues as methods for doing the following: (1) making better connections between geology and public policy; (2) incorporating systems theory into geological thinking; (3) enhancing learning environment design theory to assist learners in finding out more about natural groundwater quality; and (4) finding ways to make the teaching of geology more holistic from an ecological literacy-systems theory-environmental education perspective. These same venues can also play a role in developing better public understanding of geology. Some likely venues to pursue are shown below. Table 1 provides a preview of the description of these venues.

6.1 Training Sessions

These activities are facilitated, by persons from within or outside of the academic and/or scientific community, government agencies, environmental and civic organizations, and the business and industrial community. The facilitators are responsible for convening participants from all parties in order for them to learn about aspects of given topics (e.g., science and public policy, free-choice learning), and for developing a dialogue on these same topics.

Training sessions can be modified to fit geology, where the participants could be geology teachers and professors, licensed and non-licensed government geologists, geologists and related professionals from environmental and civic groups, geologists from the business and industrial community, and professionals and non-professionals who are interested in geology and seek to learn more about the science. All participants or groups of participants can have the opportunity to present their views of geology and why the public needs to understand the science better. The training sessions could also be run by any of the aforementioned sectors of the public, and geared towards that sector's needs; from here, a larger training session with other perspectives can be developed. The training sessions could also contain both plenary sessions, where all participants gather to hear about various methods on science and public understanding, and breakout sessions that cover a variety of topics related to geology and education.

Table 1 Venues for improving the public understanding of geology.

Venue for improving the public understanding of geology	Process involved	Main advantage(s)	Main disadvantage(s)
Professional conferences	Professional organizations convene geological scientists and/or educators from all sectors of society to present papers on topics germane to geology and/or education.	Can reach large and varied audiences of participants; Extensive learning opportunities; Professionals can strengthen their respective professions (geology and education) in their own fashions.	Focus area (education professionals): teaching and research methods (classroom, as opposed to real-world experience); Focus area (geological professionals): pure science, as opposed to applied science for geological professionals.
Professional workshops	Facilitators arrange for participants from all sectors of society (geology and education alike) to meet and learn what others in and outside of their disciplines are involved with, and what skills they can bring to the table for others in the discipline to learn about; Allows participants to share information amongst themselves, and, with the workshop facilitators.	Allows participants to learn about what their counterparts in other sectors do in their respective organizations; Possibility for all persons to learn more about what constitutes developing better public understanding of geology.	Time—much is needed to prepare professional workshop events; Subject matter—public understanding of geology is never its own topic, but interspersed with public understanding of science (education workshops) or, not represented at all (geology workshops).
Roundtable discussions	Education and/or geological professionals from all sectors of society convene at established localities to discuss topics germane to their individual uni; Commonality among participants is sought via the roundtable discussion topics.	Can help to promote better overall relations among all professionals involved; Positive relationships could also lead to potentially more attention being paid to science and public understanding—with an emphasis on geology.	Sometimes, conflicts that arise during these events could also arise at similar events at later dates—this could cause future roundtable discussions to be discontinued.
Teleconferencing and videoconferencing	Education and/or geological professionals from all sectors of society communication over long distances by telephone or television monitor; Events can be arranged by any participate in topical discussions on any discipline, as well as in setting up locations for telephone and video links.	Allows for a wide exchange of ideas; Extensive input from participants in arranging the events.	Equipment (sometimes, not all parties will receive all of the information conveyed and exchanged); Site selection (sometimes, time and space needed for teleconferencing and/or videoconferencing might not be readily available in some areas).
Training sessions	Facilitator convenes professionals in education and/or geology from all sectors of society to learn about aspects of given topics (e.g., science and public policy, informal/free-choice learning); Dialogue is developed on the topics discussed during the sessions.	Allows for an open exchange of ideas; Possibility of having thousands of ideas about improving the public understanding of geology being presented.	Highly variable levels of cooperation among participants; Some session participants may not want to share ideas; Some session participants may feel that the training session efforts are not worthwhile, due to sector-based “territorial” mindsets that some participants may bring to the table.
Web-based internet discussions	Education and/or geological professionals from all sectors of society create and maintain Internet websites with message boards; Person from all sectors of society visit these message boards and offer input on how to improve that education or geological organizations, or, speak out against these same organizations.	Can provide input, dialogue, and improvements at any Internet web site for 24 h a day.	Sometimes, information conveyed over the Internet can be outdated, distorted, misconstrued, or totally inaccurate, if the site in question is not updated periodically.

The main advantage of training sessions is that they allow for an open exchange of ideas; it is possible for at least thousands of ideas about improving the public understanding of geology to be presented at a large training session event. The main disadvantage of training sessions, however, is that the level of cooperation among participants is highly variable—there could be times where some session participants may not want to share ideas or, who may feel that the training session efforts are not worthwhile, due to "territorial" (based on sector) mindsets that some participants may bring to the table.

6.2 Roundtable Discussions

These events may be held within government agencies (Federal, State, Local), academia (schools, colleges, universities), business and industry (corporate or branch offices of companies), and civic and environmental groups (regional or district offices). Each of these parties convenes at its established localities to discuss topics germane to their individual units, and where commonality is sought among participants, via these discussion topics. This works for geology, as understanding this science has been a paramount topic to most sectors of society (e.g., protection of groundwater resources and land use).

Any of the aforementioned parties could bring up the subject of geology and get the public to understand it. This venue, while usually a local affair, could be expanded with special meetings for all sectors to have a chance to share what they discussed in their local roundtable sessions. Practices like this exist in Pennsylvania government, with the municipal and residual waste roundtables, which involve discussions of waste management topics and legal cases that occur throughout Pennsylvania—some of these involve groundwater resource protection issues; and the watershed organizations, who have their own local (river basin area) roundtable discussions, and meet with a statewide water resources committee for the main roundtable discussions.

With geology, this method could also be used, with various sectors of the public exploring ways to make geology more understandable to the public (e.g., improvements to existing publications, focusing more on the practical side of geology); from here, academia, business and industry, government, and civic and environmental groups could meet locally at first, and then meet as a larger group at a later date, to allow for more information to be shared with more participants.

The main advantage of roundtable discussions is that they can promote better overall relations among all professionals involved; such positive relationships could also lead to potentially more attention being paid to science and public understanding (focusing on geology). However, the main disadvantage of roundtable discussions is that in some cases, any conflicts that arise during these events could also arise at future events, possibly causing the roundtables to be discontinued.

6.3 Professional Conferences

These events are generally sponsored by organizations that represent various professions, such as education (e.g., AERA (American Education Research Association)) or geology (e.g., GSA (Geological Society of America)). Professionals from all sectors of the public participate in these conferences, and they specialize in a particular discipline or sub-discipline (e.g., economic geology, learning environment design theory).

At most conferences, papers on various topics within a subject are presented, along with poster sessions that provide details on research within a subject. Geology is well represented from the pure and applied science standpoint, but little appears in the area for actual public understanding (outside of the small geology-public education/public policy outlets that occur at such conferences). In any case, public understanding of geology could be the subject of interest at either educational or scientific conferences. This subject could have its own series of presentations and/or posters sessions on one or more days of a given conference. Attendees at these conferences could visit the poster sessions or hear the presentations (or both) and possibly, begin an exchange of ideas on how to improve public understanding of geology. The ideas heard during any given conference could provide material for future conferences.

The main advantage of professional conferences is that they can potentially reach large and varied audiences of participants, all of whom could learn from each other, and then use the knowledge they gain to strengthen their respective professions in their own fashions. The main disadvantage of professional conferences is that they often tend to focus upon the more traditional teaching and research methods (classroom, as opposed to real-world applications) on the education side and, more upon the aspects of research (pure science, as opposed to applied science) as on the science side.

6.4 Professional Workshops

These events are offered by government, academia, business, industry, and environmental/civic organizations, and they may be convened by facilitators within or outside of any discipline. Professional workshops allow participants to learn what others in and outside of their disciplines are involved with, and what skills they can bring to the table for others in the discipline to learn about; in short, participants learn about the activities of other organizations, both like and unlike their own. Professional workshops also allow participants to share information amongst themselves, and with the workshop facilitators.

Professional workshops on the subject of geology are convened in many sectors of the public, especially government; in most cases, the workshops are technical, covering matters ranging from water resources to providing expert testimony. Such workshops could be tailored to include a public understanding of geology component; similar workshops in education could provide this type of workshop as well. Information exchanges among workshop participants will be vital to the success and continuation of such events; such exchanges may be across sectors of the public, across geological and educational disciplines, or both.

The main advantage of professional workshops is that the process allows all professionals to learn about what their counterparts in other sectors do in their respective organizations, including the possibility for all persons to learn more about what constitutes developing better public understanding of geology. The disadvantages of professional workshops include time (workshops take a long while to prepare) and subject matter (currently, public understanding of geology is interspersed with public understanding of science on the education side, and is almost non-existent on the science/geology side).

6.5 Teleconferencing and Videoconferencing

These events involve communication over long distances by telephone or television monitor, and can be arranged by any sector of the public, and allow all sectors to participate in topical discussions on any discipline, as well as in setting up locations for links (telephone and video). Geology has been a subject of teleconferencing and videoconferencing events, but this has been more technical, with little contribution to public understanding of the science. However, public understanding of geology subject could become part of teleconferencing and videoconferencing events. Interested persons could arrange these events and offer ways to promote public understanding of geology within their own sector of the public. These methods could be shared among participants and adopted by their respective organizations, possibly brining public understanding of geology to a higher level.

The main advantage of teleconferencing and videoconferencing is that these venues allow for a wide exchange of ideas, along with extensive input from participants in arranging the events. However, the main disadvantage of teleconferencing and videoconferencing relates to equipment (sometimes, not all parties will receive all of the information conveyed and exchanged) and site selection (sometimes, the time and space needed for teleconferencing and/or videoconferencing might not be readily available in some areas).

6.6 Web-Based Internet Discussions

Communications via personal or laptop computers, Blackberries, and the Internet are standard fare in the current electronic information age. This also includes the creation and maintenance of Internet websites, which all sectors of the public have done in various organizations. Some of these websites include message boards, where any person inside or outside of any organization can offer input on how to improve that organization, or, conversely, speak out against that organization. Many organizations within various sectors of the public, including government (e.g., US EPA (US Environmental Protection Agency)), business/industry (e.g., Skelly and Loy), environmental/civic group (e.g., NRDC (Natural Resources Defense Council)), and academia (e.g., Pennsylvania State University), have message boards associated with their web sites.

For those organizations whose websites deal with education, the sciences, the environment, and the public, information about the public understanding of science, with a focus on geology, could be introduced as a component. Visitors to the site could provide feedback and/or comments about the web site, along with communicating with those they know from within their own sectors of the public, or across these same sectors; thus, the public understanding of geology could be viewed from a wide range of perspectives, and thus, its standing in the science and education realm could potentially be enhanced on a grand scale.

The main advantage to web-based Internet discussions is that input, dialogue, and improvements could occur at any web site 24 h a day. The main disadvantage, however, is that conveying information via the Internet can sometimes lead users to information that is outdated, distorted, misconstrued, or totally inaccurate, if the site in question is not updated periodically.

7. Conclusions

There is a desire among all sectors of the public to learn and understand more about the science of geology. This desire has been long-standing, for the following reasons:

(1) Geology is eclectic, drawing from other sciences, and encompasses some aspect of practically every human activity on planet Earth. The science deals primarily with objects that have their own natural histories and interpretation activities that occur during geological practices can sometimes be ambiguous, due to the varying perspectives of different geologists;

(2) Geology is also part of public and environmental policies that relate to environmental protection, including the development of organizations and publications that relate to geology directly, allowing the public to be educated about the science;

(3) Public understanding of geology can be enhanced if certain issues relating to how geological information is conveyed to and received by the public, and how the science fares in the public's "big picture" (real world) are accounted for. The role of informal/free-choice learning should also be considered here;

(4) Looking at geology through the lenses of history (development of the geological sciences over time, and their impacts), philosophy (role of varying ideas and debates about geology), and sociology (interactions between geology and socio-cultural forces) all can play a role in assisting the public in understanding this science;

(5) Attention to earth science and geology textbooks, instruction manuals for informal/free-choice learners, media outlets (newspapers, magazines, television, etc.) and earth science education pamphlets and booklets, all allow interested individuals with numerous opportunities to learn about geology on their own;

(6) The existing methods of promoting public understanding in geology can be enhanced through properly planned and executed training sessions, roundtable discussions, professional conferences, professional workshops, teleconferencing and videoconferencing, and web-based Internet discussions.

8. Future Directions

Further efforts to improve the public's understanding of geology are needed, as there is not an extensive body of research on the subject. For example, one such effort may involve variations on the elements mentioned in this paper (the science of geology, public understanding of science, HPS, methods for conveying geological information to the public, venues for improving the public's understanding of geology). These elements could be incorporated into a series of forums (topics may vary), and made available to all who wish to participate, so that no interested party will be left behind. This would be a monumental manner in which to ensure that public understanding in geology becomes a universal entity. However, whether any efforts to address and improve public understanding of geology come to fruition will depend upon the collective interests of the research community (geology, science education, environmental/public policy and the like) and, of all sectors of society.

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