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Afonso, Ana Sofia; Gilbert, John K.

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Abstract

Although an understanding of nature of science is a core element in scientific literacy, there is considerable evidence that school and university students hold naïve conceptions about it. It is argued that, whilst the failure to learn about nature of science arises from its neglect in formal science education, a major reason is the adherence to the precepts of pseudo-science, a set of beliefs that have wide cultural currency in the general population. University science and non-science students were interviewed about their beliefs in and explanations for 'water dowsing', a pseudo-scientific approach to finding groundwater. The demarcation criteria between science and pseudo-science and students' research designs into 'water dowsing' were also enquired into. The results show that many students believed in the working efficacy of water dowsing and stated pseudo-scientific explanations for it. Furthermore, they were unaware of the demarcation criteria between science and pseudo-science, and designed naïve research studies to enquire into 'water dowsing'.

Introduction

Nature of Science

Education for scientific literacy has emphasised the development of an understanding of nature of science (NOS, henceforth) (Bell, Blair, Crawford, & Lederman, 2003; Brown, Reveles, & Kelly, 2005; DeBoer, 2000; Schwartz, Lederman, & Crawford, 2004). Generally, it refers 'to the methods of science, the nature of scientific knowledge, and its institutions and social practices' (Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003, p. 717). Scientific knowledge is characterised by the following: it is tentative; it results from scientists' imagination and creativity; it is based on empirical evidence; it aims to be general and universal; it is socially constructed and it is influenced by current accepted paradigms, scientists' values, knowledge and prior experiences (Osborne et al., 2003). In order to study the world, scientists use a diversity of methods and ways of thinking, which are commonly referred to as scientific enquiry (SE, henceforth) (Lederman, 2007). Although each discipline has its own SE, there are common aspects across disciplines. These enquiry skills identify questions that can be answered by science, involve the design and conduct of scientific investigations, use adequate techniques to gather, analyse and interpret data, use evidence to generate models, and recognise and analyse alternative models. There are a number of aspects to be considered within SE: different kinds of questions suggest different kinds of scientific investigation; a range of types of models guide research; mathematics is an important tool in SE; experiments are used to test ideas; technology is used to gather data which enhances accuracy and allows scientists to quantify results; measurements are associated with uncertainty; and causation and correlation are separate but associated ideas (Bybee, 2004; Osborne et al., 2003).

Over the last 40 years, many studies have shown that there is a widespread weakness of understanding of NOS amongst school students, pre-service science teachers and science teachers (see Lederman, 1992, 2007). More recently, similar results were also found amongst university students engaged in science and engineering areas (Ibrahm, Buffler, & Lubben, 2009; Palmer & Marra, 2004; Ryder, Leach, & Driver, 1999; Thoermer & Sodian, 2002).

In the light of these results, systematic and sustained efforts have been made to teach NOS. Implicit and explicit teaching approaches have been designed. In the implicit teaching approach, the effective understanding of NOS is the outcome of guided hands-on enquiry-oriented activities. In the explicit teaching approach, the diverse dimensions of NOS are overtly addressed and reinforced by reflective practical experience of their use (Bell, 2004; Khishfe & Abd-El-Khalick, 2002; Khishfe & Lederman, 2006).

Research with students and science teachers suggests that the implicit approach has had a limited outcome, whilst the explicit approach seems to be more successful (Abd-El-Khalick & Lederman, 2000; Bell, 2004; Khishfe & Abd-El-Khalick, 2002; Khishfe & Lederman, 2007). Evidence for the success of explicit approaches in the context of SE was also reported in studies with university science students (Ryder et al., 1999; Schwartz et al., 2004) and with high-ability secondary science students (Bell et al., 2003). Ryder et al. reported that final-year university science students improved their images of science after engaging in a 5-8 month-long science project in which discussions on NOS occurred spontaneously and routinely. Factors enhancing this understanding were: 1) the nature of the research projects undertaken, for they involved an epistemological focus rather than only experimental practical work; 2) the explicit instructional approach on NOS that accompanied the projects; and 3) students' exposure to a culture of research practice in a research laboratory. Similarly, Schwartz et al. (2004) found that pre-service secondary science teachers, enrolled in a 5-year MA in science teaching, improved their understanding of NOS after a research internship course which included a research component, seminars and journal assignments. Some factors enhanced an understanding of NOS: 1) the opportunity for reflection on NOS; 2) the context of the interns' research, even though their role was peripheral; and 3) the interns' perspective on the research.

In spite of the promising effectiveness of explicit approaches of several kinds, they seem to be of limited success because students disregard the creative and imaginative aspect of NOS (Khishfe & Abd-El-Khalick, 2002) or its subjective, social and cultural dimensions (Akerson, Abd-El-Khalick, & Lederman, 2000; Solomon, Duveen, Scot, & McCarthy, 1992). The relative failure of attempts to teach NOS relates to the tenacity of individuals' views on NOS and/or to the content and context of teaching NOS (Akerson et al., 2000; Khishfe & Abd-El-Khalick, 2002). These authors suggest that this relative limitation of the explicit approach can be overcome by integrating the explicit reflective instruction within a complete conceptual change approach. In that, the learner must feel dissatisfied with the explanatory value of existing knowledge (Posner, Strike, Hewson, & Gerzog, 1982) and needs both a personal emotional drive and a socially-supportive context for successful conceptual change to take place (Pintrich, Marx, & Boyle, 1993). The belief, widespread throughout all communities in all countries, in what is often called 'pseudo-science', seems to be a suitable context for learning NOS because it appeals to students' interest. Also, it is socially and personally relevant as individuals often have to deal with pseudo-scientific information in their everyday life, e.g. the use/non-use of complementary alternative medicines (CAM). Moreover, it provides a window into the individuals' epistemological perspectives, since a good grasp of NOS is essential to differentiate science from pseudo-science (Martin, 1971; Matthews, 1998). On the other hand, we suggest that the adherence to the precepts of pseudo-science may restrict the use of arguments based on NOS and constrain its full understanding. This is because the beliefs constitute exemplars of events which may be retrieved to make sense of new situations, these calling for the use of epistemological knowledge in their evaluation. Indeed, it is known that 'health science' students' attitudes towards CAM correlate positively with their beliefs in paranormal phenomena (Petterson & Olsen, 2007) and that individuals with higher degrees in science use CAM, based on their beliefs about the efficacy of the treatment rather than on the scientific information available (Astin, 1998). It is only when we know the nature and extent of such pseudo-scientific beliefs that more fully effective teaching of the NOS can take place.

Pseudo-scientific Beliefs and their Incidence

Pseudo-science is often defined as 'claims presented so that they appear scientific even though they lack supporting evidence and plausibility' (Shermer, 1997, p. 33). The problem of demarcation (i.e. the differentiation between science and non-science), has been discussed by several philosophers of science (such as Popper, Kuhn, Lakatos, or Laudan) who point out different demarcation criteria. Popper proposed falsification (Popper, 1953/1998). Kuhn based his argument on the existence or absence of a paradigm (Gieryn, 1995). Lakatos assumed a knowledge-growing criterion (Hacking, 1981), and, for Laudan (1981), the demarcation is between well-confirmed and poorly-confirmed knowledge because the difference between types of knowledge is a matter of degree rather than of kind.

Although there is not a sharp break between science and pseudo-science, this differentiation cannot be seen just as a matter of degree, since science has acquired a cognitive status and authority rarely achieved by other forms of knowledge regarding the representation of the world (Gieryn, 1995). Science can be seen as a space whose boundaries are not rigid but are constantly being negotiated as science gradually expands its scope of exploratory capacity (Derksen, 1993; Gieryn, 1995; Lugg, 1995; Reisch, 1998; Thagard, 1993). Consequently, the differentiation between science and pseudo-science is not clear-cut but rather a continuum. For example, acupuncture, defined as the stimulation of specific points in the body by subcutaneous insertion of needles (Sjölund, 2005), was once regarded as pseudo-science (Allchin, 1996), but now has a limited scientific acceptance following careful controlled experiments (Jones, 2002).

Despite this continuum, it is possible to build a prototype of pseudo-scientific knowledge, based on the following typical characteristics: the neglect of disconfirmatory evidence, the existence of a pool of knowledge which does not expand with experience, reliance on a single theory and the absence of evaluation of existing theories, the formulation of ad hoc hypotheses to explain anomalous results, the lack of control studies (Marks, 1986; Thagard, 1993), and the use of obscure language in describing phenomena (van Rillaer, 1991). None of these features alone constitute demarcation criteria, but they do represent warning signs of the presence of pseudo-science and must be analysed within each particular context (Thagard, 1993).

Different studies (National Science Foundation, 2006; The Times, 2007) provide evidence that pseudo-scientific beliefs are widespread. Whilst there is insufficient evidence to conclude that these beliefs are held as a consequence of explicit reliance on pseudo-science, the individuals concerned must have some, necessarily non-scientific, grounds for their trust.

Groundwater Identification

Groundwater Identification: Scientific and Pseudo-scientific Approaches

Groundwater constitutes 30% of fresh water available on Earth (Carvalho, 2006) and it has been exploited in periods of water shortage. In several parts of the world its exploration for it has been conducted using both scientific and pseudo-scientific approaches, the latter having a very long historical provenance. Governments (the Portuguese government among them) have passed laws which place responsibility of groundwater identification in the hands of experts (Law no. 133/2005).

In contemporary hydrology, groundwater identification involves the visualisation of targeting areas making use of Earth-orbiting remote sensing techniques jointly with a Geographical Information System and hydrogeological models (Howari, Sherif, Singh, & Al Asam, 2007). Once the potential zones for groundwater exploration are identified, geophysical techniques are often used to take decisions on drill-hole positioning (Kirsch, 2006), to anticipate the behaviour of different types of aquifers, or to detect other hydrological structures (Carvalho, 2006).

Geophysical techniques encompass the measurement of physical properties of the earth' crust by employing approaches such as: the seismic method, which is based on phenomena of reflection and refraction experienced by electromagnetic waves, as a result of changes in velocity during their propagation (Patra, 2001); the geoelectrical method, which measures the electrical resistivity of the ground – found by applying electric currents and measuring potential differences on the surface (Patra, 2001); or Nuclear Magnetic Resonance (NMR), a method which depends on the behaviour of the protons in the hydrogen atoms in the water. This involves disturbing the spin of the nuclei by an electromagnetic pulse and the analysis and measurement of the response signal after pulse cut-off. NMR has important advantages in relation to other geophysical procedures because it detects water directly, provides estimations of mobile water volume and hydraulic conductivity, revealing the depth and areas of aquifers (Yaramanci & Hertrich, 2006).

Pseudo-scientific procedures, known as dowsing or witching, are applied by individuals, namely dowsers, who claim the ability to find groundwater when they cross a field holding tools such as a dowsing rod (i.e. a forked wooden stick) or a pair of L-shaped metal rods (Foulkes, 1971). In the first approach, the classical one, the forked rod is held in both hands with the butt end of the fork pointing up. When the butt end of the fork bends downwards, the dowser claims the presence of groundwater (Deming, 2002). In the second approach, a metal rod is held in each of the dowser's hands, parallel to the ground and to each other. In the presence of groundwater the two metal rods are said to cross.

The efficacy of water dowsing has been explored but the controlled experiments have showed results that are no better than would be achieved by chance or guesswork (Enright, 1995, Foulkes, 1971). Consequently, the scientific community currently accepts that water dowsing is pseudo-scientific phenomenon (Carvalho, 2006).

Research Questions

This study aims at describing the nature and extent of science and non-science students' beliefs in water dowsing and at analysing students' views and use of NOS in this pseudo-scientific context. For that, the following research questions guided this research:

1. How did participants judge the working status of water dowsing?
2. How is water dowsing explained by students who judged it as an effective approach?
3. How did participants judge water dowsing's scientific status?
4. Which criteria do the students state regarding the demarcation criteria between science and pseudo-science/non-science?
5. How would participants enquire scientifically into water dowsing?

Methodology

Sample

The sample comprised 45 Portuguese university students attending University of Minho. It consisted of: 13 postgraduate students enrolled in the first year of a two year MSc in Physics Education, of age range between 23 and 33 years, all were engaged in scientific themes for their dissertations in the second year of the course; 12 undergraduate students of civil engineering; 20 undergraduate students of arts. The undergraduate students were between 21 and 26 years old and were enrolled in the fourth year of a five year degree. Of the 45 students, 22 were female and 23 were male, 16 had grown up in a rural area and 29 in an urban area. None of the students had attended a formal course on the epistemology of science. Students of civil engineering and physics education were chosen because their formal background in physics should in principle allow them to understand the scientific principles underlying the approaches to groundwater identification. Furthermore, students of civil engineering have, according to Law no.133/2005, the scientific requirements to enable them to pursue a career in hydrological engineering and groundwater identification. Hydrology is a component of civil engineering syllabus but approaches to groundwater identification is absent from this course.

The students of arts were chosen as a comparison group because of the very different nature of their studies i.e. they certainly did not encounter discussion of NOS or groundwater identification. The only formal science education they had encountered is at the compulsory school level.

Data Collection and Analysis

Data was collected during 2006/2007 and 2007/2008 academic years by using individual semi-structured interviews (Appendix 1). This period of data collection was necessary due to the low number of students who engage in a MSc in Physics Education, and to the difficulty in engaging students of arts in an interview that is related to science. The physics and civil engineering students attended the classes of one of the authors. The students of arts were recruited on the Arts Floor in the University Library.

All the interviews were recorded and fully transcribed. The students were divided into two groups, science and non-science students, according to their formal university background in physics. In the science students' group are those of civil engineering and of physics education; in the non-science students' group are those of arts. A code was attributed to each interview. It is composed by a letter, identifying a course of studies (i.e. MP, master in physics; UC, undergraduate in civil engineering; UA, undergraduate of arts), and a number identifying the student in each group. Each interview was read separately in order to gain a holistic understanding of students' ideas. The data was then analysed in order to find patterns in it and to distinguish between typical and atypical cases (Erickson, 1998). Elements of NOS as described by Osborne et al. (2003) were searched for in the data. The data was organized under three main themes 'the nature and extension of students' beliefs in water dowsing', 'scientific status of water dowsing and demarcation criteria between science and pseudo-science' and 'design of scientific enquiry' which were related to the aims of this study. The second and third themes provide hints into students' understanding and use of aspects of NOS in the context of water dowsing. Within the first theme, there is a description of students' beliefs in the working status of water dowsing, the reasons for that judgment, and the believers' explanations for the apparent success of water dowsing. Students' judgments on the efficacy of water dowsing were classified as it being 'effective', 'ineffective' or 'unable to judge'. Effective judgments were based on personal experiences or on resemblance reasoning, as the following quotes illustrate:

> *Reason based on personal experiences* – I do believe (in it) because of my family history. Maybe because my grandfather was a dowser, I readily believe in this tool.' (UC1); 'I heard about it (water dowsing) in my village; the elderly men have their own approaches.' I do believe in it.' (UA5).
>
> *Reason based on resemblance reasoning* – 'This reminds me the way elephants search for water by using their trunk to identify humidity on the ground.' (UA12); 'I never heard about it (water dowsing) but I do believe in it. Archaeology tells us that, from ancient times, humans have survived and have adjusted to their environment by developing techniques.' (UA14)

Ineffective judgments were based on the nature of the dowsers' tools or on aspects of NOS, as the following quotes illustrate:

> *Reason based on the nature of dowsers' tool* –'I don't think that two sticks will be able to identify water!' (UA3).

Reason based on aspects of NOS – 'I don't know which theory the stick's behaviour is based on!' (MP7); 'What are its principles? There is nothing that supports these ideas!' (MP6); 'I don't believe. It's not scientific knowledge. It wasn't studied by scientists' (UA15).

Explanation for the apparent success of water dowsing, when provided, were categorised as 'involving scientific ideas' or 'new-age ideas'. Exemplars of quotes categorised as:

Involving scientific ideas – 'I have a faint idea of an explanation related to the polarity of the water molecules. I think it has to do with the electric charges.' (UC6); 'The rod must move due to a magnetic field.' (MP1).

'New- age' ideas – 'That's the energy of the rod searching for the energy of the water. I don't know. It's supernatural' (UA1).

An analysis on students' judgment of the scientific status of water dowsing was undertaken. They categorised it as 'scientific knowledge', 'traditional knowledge', and 'unable to evaluate'. In addition, a description of students' demarcation criteria and an analysis of non-believers' opinions about whether or not water dowsing might become scientific knowledge was obtained. For this analysis, (in)adequate aspects of NOS were searched for in the students' answers. Exemplars of quotes are:

'This is traditional knowledge because scientific knowledge is certain, precise and can be applied in several situations.' (UC9), 'This is a phenomenon but not a scientific one because there is no explanation for its success' (MP8), 'to be scientific knowledge, this method needs to be precise. Sometimes, the rod fails the location of the water' (UC7)

(In)adequate aspects of NOS, particularly concerned with nature of SE, were also searched for in the data that was concerned with students' descriptions on how one would scientifically enquire into water dowsing. Designs were categorised into: 'interviews in the rural communities', which suggests that science does not require evidence; 'empirical designs'; 'impossible to enquire', underlying the idea that beliefs cannot be tested by science; and 'unable to enquire'. When students suggested an empirical design, three types of enquiry were described: 1) 'naïve empiricism', underlying the views that scientific knowledge is based on a single datum or only aims at collecting confirmatory data; 2) 'experimental design', when there is an (in)sufficient control of variables; and 3) 'testing models. Exemplars of quotes which illustrate these categories are:

Interviews in the rural communities – I would combine my ideas with the testimonies of other people.' (UC2)

Naïve empiricism – I would perform the experiment in an unknown field. Someone will tell me: 'In this field there is groundwater. Can you find its location?' I will search for water. Eventually, the rod bends. I will say: 'there is water here'. If this location is confirmed by the enquirer, I will agree with the procedure (of water dowsing). (MP1)

Experimental design – 'After selecting different types of soils (e.g. alkaline, with and without water), I would characterise the atmospheric pressure over those soils as well as the depth and different rate of water flow. Then, I would attach a dynamometer to the free extreme of the rod in order to measure its deflection during groundwater identification.' (MP7)

Testing models – 'Since this (water dowsing) works, there must be an explanation. Maybe related with some property of the water or soil. So, I would find several theories and I would analyse which one best explains the efficacy of the rod.' (UA19)

Impossible to enquire - ‘This is a belief. So, either you believe it or not. This is like God either you believe in his existence or you don’t. For example, scientists base their ideas about the origin of the world on data; while Catholics believe the world was created by God. For scientists this latter idea is absurd because they cannot prove it.’ (UA15)

Even though this is a qualitative study, in a few cases, the exact Fisher's test was used to to see if there are significant differences between the frequencies across the identified themes. This test was chosen due to the small size of the sample. With this test, it was possible to calculate p-values and to analyse whether or not there is evidence to reject, at the usual significance levels (0.1; 0.05; and 0.01), the hypothesis of independence between the students’ groups (Rohatgi, 2001).

Results

The Nature and Extension of Students’ Beliefs in Water Dowsing

This section analyses the students’ judgment of the working efficacy of water dowsing and the reasons for their judgment. The nature of the explanations provided for the apparent success of water dowsing will also be discussed.

Believing or nor in water dowsing seems to be independent of students’ group ($p=0.748$). In judging the working status of water dowsing, about 40% of the students classified it as ‘ineffective’ (Table 1). This classification, which was frequent amongst students unfamiliar with water dowsing, was justified differently by non-science and science students. While most of the science students who employed aspects of NOS disregard water dowsing (pointing out that scientific knowledge is embedded in a community of practice, it aims to be general and universal, it is based on models); the non-science students focused their judgment on the nature of the dowsers’ tools:

> ‘I believe in things that I study, that come in books. But dowsing is transmitted from one person to another in rural communities. I don’t give too much credibility to this knowledge which wasn’t provided by scientists and isn’t published. Besides, science is universal and so this method should work everywhere, not only in a backyard!’. (MP11)

> That’s weird, I don’t believe in it (because) it’s just a rod! An olive-rod. (UA9)

[Insert Table 1 about here]

On the other hand, similar reasons were employed by science and non-science students to justify their beliefs in the efficacy of water dowsing. These reasons were linked to students’ personal experiences, which came from situations outside the formal educational system – namely, enculturation, story-telling, or casual observations. For some students (9 out of 45) water dowsing is sustained and perpetuated in rural communities in which they grew up, becoming part of their culture. Consequently, the ancient tradition of water dowsing was seen as a reason for success:

> UC10: I’m not from the city. I’m from a village and I’m used to popular methods!
>
> Interviewer: Is water dowsing a working effective approach?
>
> UC10: Rural people have survived using this tool, so we must learn with them.

> UA6: I heard about it in my village; the elderly men have their own approaches.
>
> Interviewer: Does water dowsing work?
>
> UA6: Yes. I don’t have any explanation for that but if they (elderly men) use it, it’s because it works.

Other students (10 out of 45) justified the working efficacy of water dowsing by recalling either stories about this approach or single, and evidently memorable, observations of it. Often, the trust placed on the narrator of successful dowsing stories or on the dowser, with whom the students had affective links, triggered emotional responses, enhancing their beliefs:

> Interviewer: Couldn't it be that your father identified groundwater by chance?
>
> MP12: He identified not one but two places. We're talking about my father. He was a primary teacher. He doesn't fool around. He studied in a seminary, he still knows Latin. Besides, none of the wells ever dried, not even during the dry period of the 80's.

> 'I never saw the procedure but my friend told me about it and I know he wouldn't lie.' (UC11)

A few students (3 out of 45), who had never heard about water dowsing before the interview, argued in favour of its working effectiveness by using resemblance reasoning (Table 1):

> MP9: There are so many weird things that happen.
>
> Interviewer: Can you give examples?
>
> MP9: In this situation, it's the water that causes the bending of a rod. Similarly, if you cut your hair during full moon, it will grow faster and stronger.

Providing or not an explanation for the apparent efficacy of water dowsing seems to be dependent on the students' group ($p=0.015$). Many students (54.5%), mainly from the non-science group, seem to believe that seeing is knowing, since they were unable to articulate the apparent success of water dowsing with a model that could explain it. Most of the explanations provided were based on a poor understanding of both scientific ideas, such as the polarity of water molecules or magnetic fields, and the phenomena associated with them (Table 2).

'Water dowsing is related to the water humidity ... not humidity, electricity. The water is composed of molecules with uneven polarities – what is their name? I learnt that in chemistry - which attract the rod.' (UC1)

'Between the rocks there is a flow of water, right? These rocks have radiation, they have natural magnetism. So, the middle part of the stick is pulled towards the ground, in the direction of the water. This is like the compass. The compass needle is attracted to the North Pole like the middle part of the stick is attracted to the ground.' (UC10)

[Insert Table 2 about here]

Although rare, two students provided new-age type of explanations:

MP12: (…) I believe in energy inside us. There is a source of energy inside us and my father does have it.

Interviewer: What do you mean with a source of energy?

MP12: I would not say intuition or light. I don't know how to explain because I don't have this. I'm a Christian Catholic, so I can only think in terms of energy.

Scientific status of water dowsing and demarcation criteria between science and pseudo-science

Most of the students who believed in the effectiveness of water dowsing classified it as traditional knowledge (68.0%) because it was related to the traditions and life style of the rural people (Table 3).

[Insert Table 3 about here]

Water dowsing was classified as either scientific knowledge or traditional knowledge, independently of students' group (p=0.485). Different criteria were used to demarcate traditional from scientific knowledge by both groups of students. However, few aspects of NOS were mentioned for differentiating science from non-science and many of them underlined inadequate views of NOS. Inappropriate views of NOS encompass the idea that scientific data must be quantitative and that scientific measurements are associated with certainty:

> 'It isn't a scientific approach because it doesn't provide values. It doesn't measure the quantity of water or its depth. It also doesn't provide information about the nature of water. It simply states that there is water. I am not saying that scientific approaches always provide direct measures, but by using formulas it is possible to quantify.' (UC10)

> 'Dowsing works several times but it is not 100% effective. So, for me it is not a scientific approach, I don't think it will be possible to build a groundwater map, for instance, using this approach.' (UC6)

On the other hand, some participants seem to hold adequate beliefs concerned NOS. In particular, how scientific knowledge needs to be recognised by the scientific community, the fact that the generation of scientific knowledge does not result simply from the accumulation of real-life observations, and the idea that scientific knowledge has an explanatory power. The following quotes illustrate these aspects:

> '(…) I don't think water dowsing was approved by those international scientific institutions that certify knowledge.' (UC8)

'No, I would not classify it as scientific. These are rudimentary instruments, they don´t have the approval of the scientific community. These are personal techniques used by the rural old people.' (UA6)

'Rural experience is transmitted over generations often by observation. For example, a builder knows that in a right triangle whose legs are respectively 3 cm and 4 cm, the hypotenuse will measure 5 cm. He knows the sequence – 3, 4, 5 – but he may not know why. While in science we know the Pythagorean theorem.' (UC9)

'No. I don't think it's scientific (...). It comes from ancient times and is transmitted from person to person. In addition, dowsers did not study water dowsing and are unlikely to know why it bends. But they know it works. On the other hand, scientists may have an explanation for dowsing which can justify its efficacy'. (UA7)

Amongst those students who rejected the efficacy of water dowsing, only science students expressed the view that the boundaries between science and non-science are not rigid and can change as a consequence of empirical tests. Therefore, students recognised that water dowsing's working status is an issue that can be analysed by science, in which the collection of empirical data is a core activity. Nonetheless, few of these science students mentioned that scientific knowledge also requires the articulation of the empirical data with a plausible mechanism of action in agreement with existing scientific knowledge, as the following quotes show:

'Something that is scientific can be proved trough experiments. So, if we can prove that a stick attracts water, it may be!' (MP5)

'I don't know much about dowsing. Nevertheless, if someone shows its credibility and explains why it works, then I will consider it.' (UC12)

On the other hand, non-science students did not show openness to an investigation on water dowsing. They were either unable to analyse this issue or suggested that it cannot possibly become scientific knowledge:

Interviewer: Can water dowsing ever become scientific knowledge?

UA18: (Laugh) No, I cannot imagine that!

Interviewer: Why not?

UA18: It's too rudimentary.

Design of scientific enquiry

Independently of students' group, the designs proposed have an empirical nature (p=0.635). However, most of these empirical designs (64.5%) reflect inadequate views of SE' nature. Naïve empiricist views of SE were the most frequent amongst science and non-science students (Table 4). Their designs aimed at either collecting a single datum to support prior beliefs or at collecting a large quantity of data disregarding their validity. Besides, students often did not recognise methodological inconsistencies in their designs when they were questioned, illustrated by the following quotes:

UA2: I would do this near a well. By moving towards it, the rod would increase its bending.

Interviewer: Can your enquiry be fraudulent because you did it near a well?

UA2: (laugh) Maybe. But if a sceptic has the opportunity to hold the rod, he will see that the bending is real.

MP12: There is nothing better than seeing demonstrations by dowsers both in the north of Portugal, in a granite soil, and in the centre and south in a limestone soil.

Interviewer: Can the dowsers' success be explained by their familiarity with the field?

MP12: It's not easy to visualise groundwater. As far as I know, small soil vibrations can change the course of a water vein.

[Insert Table 4 about here]

A small number of students in both groups (20.0%) proposed either designs aimed at testing exploratory models or experimental enquiries. An example of the former is the following quote:

'I would measure the dowsers' characteristics. We can imagine a model in which the dowser is a medium of transmission of something. So, it must be possible to measure some kind of changes in the dowsers' bodies, such as electric or magnetic, while the rod bends. Of course the measurements need to be carried out with instruments that are scientifically accepted.'(MP13)

The experimental enquiries proposed would not produce reliable evidence to access the effectiveness of water dowsing. Students would carry their experiments in the field, except one student who proposed laboratory experiments:

'I would build a model. A platform under which there's running water in some places but not in others. By crossing the platform with a rod we can analyse whether or not it bends. Of course, this procedure needs to be repeated several times. If the rod bends in all the experiments or in the majority of them, then it's credible.' (UC12)

Experiments designed to take place in the landscape exhibited several problems including inadequate sample size, unsuitable control treatments, bias due to the presence of sensory clues, lack of double-blind tests, non-randomized tests, and absence of replicability. When students revised their designs, they only mentioned the need to collect more data:

MP8: I would analyse the behaviour of a rod in two places, with and without water.

Interviewer: What would you conclude if the rod bent in the location with water?

MP8: Nothing. I would need to carry out more tests in places with and without water, in order to calculate the frequency of the bending of the rod. A percentage of at least 80% would indicate a credible approach.

UA13: We would use a scientific instrument to find two places: one with and another without water. Then, the dowser would be asked to analyse whether or not there was water in those places.

Interviewer: What would you conclude if the rod bent in the location of water?

UA13: That the rod works.

Some students (9.0%) did not recognise that scientific approaches require the use of experimental methods. They suggested enquiries that were social in nature, in which members of the rural communities would be interviewed about cases of success or available explanations for water dowsing, which would then be scrutinized for scientific soundness:

‘I would hear the dowsers’ explanations. After analysing them from a scientific point of view, I would conclude (something) about water dowsing’s effectiveness.’ (MP6)

‘This is a task for ethnography, which studies the traditions and the living style of people. So I would go to a village and I would talk to the old people.’ (UA14)

Discussion

The use of interviews as the vehicle for data collection inevitably led to a constrained number of individuals being sampled. Nevertheless, this exploratory study provides some insights into students' beliefs about the nature and extension of science and non-science in water dowsing and into the aspects of NOS employed by students in the analysis of this context.

The Nature and Extension of Beliefs in Water Dowsing

This study supports the idea that beliefs in pseudo-science are not restricted to non-science students (Astin, 1998; Walker, Hoekstra, & Vogl, 2002). Like in paranormal beliefs (Blackmore, 1997; Glicksohn, 1990), personal affective experiences often enhance students to believe in the working effectiveness of water dowsing. In addition, these personal experiences also seem to constrain the use of NOS to critically assess this pseudo-scientific issue. Indeed, students unfamiliar with water dowsing often disregarded its effectiveness and science students employed known aspects of NOS to justify their opinion. On the other hand, science and non-science students, considering the efficacy of water dowsing, often accepted it on face value and used similar affective reasons, logically not relevant to the analysis of the situation, to support the apparent success of this groundwater identification approach. These results are consistent with those of other studies which reported that the use of logical arguments has a larger effect on unbelievable information than on believable information (Newstead, Pollard, Evans, & Allen, 1992) and there is a trend to accept conclusions in agreement to one´s beliefs regardless of their validity, i.e. the belief - bias effect (Astin, 1998; Thompson, 1996).

The belief - bias effect is justified by the individuals' failure to search for alternative representations of the situation in analysis (Torrens & Thompson, 1999). Since the search for alternatives requires questioning one's beliefs or ignoring its existence (Torrens &

Thompson, 1999), the adherence to water dowsing efficacy can result from an amalgam of several factors: 1) its origin, namely enculturation because questioning water dowsing may cause significant psychological impact, such as threatening the self, the sense of belonging, or the social relationships with others (Kelly, 1955; Menon, 2000); 2) lack of understanding of NOS, reflected on some students' inability to provide an explanation to water dowsing which seems to encapsulate the idea that seeing is believing; 3) an undeveloped understanding of scientific knowledge, namely magnetic fields and polarity of water molecules which were used by some science students to explain water dowsing; or 4) the acceptance of new-age philosophy.

Students' Views and Use of Aspects of NOS in the Context of Water Dowsing

Students who believed in the working efficacy of water dowsing often classified it as traditional knowledge. However, this classification was also a window into students' views of NOS. Science and non-science students held a fragmented view of NOS. First, they were unaware of the demarcation criteria between science and non-science; and, secondly some held inadequate views of SE' nature, namely that scientific measurements are associated with certainty and data must be quantitative.

Amongst students rejecting the efficacy of water dowsing, non-science students were often unable to assess whether water dowsing may, or may not, become scientific. Consequently, they show difficulties in differentiating claims that can be testable from those that cannot be testable by science. Conversely, science students believe that science borders can change as a consequence of empirical tests.

Complementary misconceptions on SE' nature were found when science and non-science students were asked to enquire water dowsing scientifically: 1) empirical enquiries were not seen a requirement of SE, since some designs were of a social nature only; 2) like in the context of paranormal beliefs (Dragnall, Parker, & Munley, 2007), most of the designs proposed by believers were empirically naïve , aimed at collecting selected data that could support water dowsing apparent efficacy without having in consideration the validity of the data; and 3) enquiries under controlled conditions did not follow the guidelines of ‘exploratory experimentation’ (Steinle, 1997) because the sample size was inadequate, replications of results were not suggested, and biases and random influences from the environment were not minimized. Reasons for these inadequate views on SE’ nature may be linked to the lack of an epistemological course, in which they could engage explicitly with NOS, a requirement for its effective understanding (e.g. Lederman, 2007). Furthermore, these designs suggest a distortion of the meaning of evidence or a difficulty in transferring this concept from formal education to everyday contexts. This may be explained by the little emphasis given to the concept of evidence in science education (Gott, Duggan, & Johnson, 1999), particularly as it is often attributed with the status of skill rather than conceptual knowledge (Aikenhead, 2005).

Conclusion

Science and non-science students, accepting or rejecting the efficacy of water dowsing, often held inadequate and fragmented views on NOS, particularly on SE’ nature. Consequently, these students seemed to be vulnerable to pseudo-science either because they held a poor grasp of NOS (Matthews, 1998) or because the belief-bias prevented them from using accepted knowledge on NOS to critically assess pseudo-scientific situations in which they believe.

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Appendix

Questions Used During the Interviews and their Relation to the Research Questions (RQ)

1. Have you ever heard about water dowsing? If so, can you describe it? If not, I would like you to look at these pictures (pictures showing 'dowsers'). Do you have any idea what they are illustrating? (RQ1)

   If water dowsing is recognised in question 1 then

   1.1. What do you know about this procedure? (RQ1)

   1.2. Where did you learn about it? (RQ1)

   1.3. Have you ever seen water dowsing in operation? Where? (RQ1)

   1.4. Have you ever tried water dowsing? If so, Can you describe your experience? (RQ1)

   If water dowsing is not remembered on question 1, water dowsing is described.

2. How would you judge the working status of water dowsing? Why? (RQ1)

   2.1. (If it is judged as effective), How would you explain its working efficacy? (RQ2)

3. How would you judge water dowsing in terms of its scientific status? Why? (RQ3)

   3.1. (If water dowsing is not judged as scientific knowledge) what makes this procedure different from a scientific one? (RQ4)

   If it is judged as ineffective,

   3.2. Can water dowsing ever become scientific? Why? (RQ4)

4. How would you enquire scientifically into water dowsing? (RQ5)

   If the design is not consistent with a randomized controlled experiments

   5.1. Imagine that (the behavior of the rod is described) what would you conclude? (RQ5)

   5.2. Can a sceptic argue that your design is fraudulent because.....? (RQ5)

Table 1

Reasons put forward by science and non-science students for judging the working status of water dowsing (f=45)

Judgement	Reasons	Science n=25	Non-science n=20	Total %
Effective	Personal experiences	13	6	42.0
	Use of resemblance reasoning	1	2	7.5
Ineffective	Inconsistent with NOS	9	2	24.0
	Nature of the tool	1	6	15.5
Unable to judge	-	1	4	11.0

Table 2

Explanations provided by science and non-science students for the apparent success of water dowsing (f=22)

Explanations	Science n = 14	Non-science n = 8	Total %
Involving scientific ideas	8	-	36.5
New-age ideas	1	1	9.0
Unknown	5	7	54.5

Table 3

Judgement of the scientific status of water dowsing by believers (science and non-science students) (f=22)

Scientific status of water dowsing	Science n = 14	Non-science n = 8	Total %
Scientific knowledge	2	-	9.0
Traditional knowledge	8	7	68.0
Unable to judge	4	1	23.0

Table 4

Types of enquiry designs presented by science and non-science students (f=45)

Types of enquires	Science n = 25	Non-science n = 20	Total %
Interviews in the rural communities	3	1	9.0
Empirical designs			
Naïve empiricism	17	12	64.5
Experimental design	4	3	15.5
Testing models	1	1	4.5
Impossible to enquiry	-	1	2.0
Unable to enquiry	-	2	4.5