Sci & Educ
https://doi.org/10.1007/s11191-017-9952-9

ARTICLE

Connecting Inquiry and Values in Science Education

An Approach Based on John Dewey's Philosophy

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Abstract Conducting scientific inquiry is expected to help students make informed decisions; however, how exactly it can help is rarely explained in science education standards. According to classroom studies, inquiry that students conduct in science classes seems to have little effect on their decision-making. Predetermined values play a large role in students' decision-making, but students do not explore these values or evaluate whether they are appropriate to the particular issue they are deciding, and they often ignore relevant scientific information. We explore how to connect inquiry and values, and how this connection can contribute to informed decision-making based on John Dewey's philosophy. Dewey argues that scientific inquiry should include value judgments and that conducting inquiry can improve the ability to make good value judgments. Value judgment is essential to informed, rational decision-making, and Dewey's ideas can explain how conducting inquiry can contribute to make an informed decision through value judgment. According to Dewey, each value judgment during inquiry is a practical judgment guiding action, and students can improve their value judgments by evaluating their actions during scientific inquiry. Thus, we suggest that students need an opportunity to explore values through scientific inquiry and that practicing value judgment will help informed decision-makings.

1 Introduction

Science structures our everyday world and impacts us almost every moment of our lives. At some point, we all must wrestle with how to understand, evaluate, and make use of scientific results and methods. Naturally, we expect that science education will make us scientifically literate and prepare us to make informed decisions about issues where science plays a role.

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Published online: 05 January 2018

Although science education has relied on many competing definitions of science literacy throughout its history, these definitions generally agree in describing science literacy as "what public should know about science in order to live more effectively with respect to the natural world" (DeBoer 2000, p. 594). In this respect, science literacy includes "being familiar with the natural world…; understanding some of the key concepts and principles in science; having a capacity for scientific ways of thinking… and being able to use scientific knowledge and ways of thinking for personal and social purposes" (Rutherford and Ahlgren 1990, p. x). Today, we increasingly face *socio-scientific issues*, complicated decisions that are intertwined across science, society, culture, environments, and politics; thus, science teachers must bring such socio-scientific issues to the classroom for students to achieve science literacy applicable to our contemporary social context (Zeidler et al. 2005).

The core activity of scientific practice is scientific inquiry. Inquiry has long been emphasized in science education, and this emphasis is expected to help students understand, evaluate, and make informed decisions about socio-scientific issues (American Association for the Advancement of Science [AAAS] 1993, pp. 3–20; Rutherford and Ahlgren 1990, pp. 3–13). K-12 science education has focused on educating all citizens, and people who are well educated in science, whether they are scientists or non-scientists, are expected to possess "scientific habits of mind, capability to engage in scientific inquiry, and [to know] how to reason in scientific contexts" (National Research Council [NRC] 2012, p. 3-1). Eventually, scientifically literate people are expected to make informed decisions when they face a controversial socio-scientific issue. Doing scientific inquiry in science class, however, does not significantly contribute to students' decision-making in such cases, contrary to expectations. When students make arguments or decisions about socio-scientific issues, they use personal, social, and cultural values. When students engage in scientific inquiry, they seem to think that scientific inquiry is a value-free process for learning facts (Grace and Ratcliffe 2002; Lee 2007; Rundgren et al. 2016). In these cases, values become the term that disconnects scientific inquiry from decision-making in socio-scientific issues.

Values, however, play a role both in decision-making about socio-scientific issues and in scientific inquiry because science is a value-laden human endeavor (Anderson 2004; Biddle 2013; Douglas 2000, 2009; Kourany 2010; Longino 2002). This does not mean that science is not conducted objectively. In fact, science is strongly guided by cognitive or epistemic values such as objectivity, accuracy, precision, consistency, scope or unifying power, explanatory power, fruitfulness or fertility, testability, generality, and simplicity (Allchin 1999; Douglas 2013; Kuhn 1977; McMullin 1983). These science-specific values are also known as "constitutive values" (Longino 1990, p. 4). These values are generally contrasted with those called "non-cognitive" (Pournari 2008, p.669), "non-epistemic" (Pournari 2008, p.674),[1] or "contextual" (Longino 1990, p. 4) values, including personal, social, and cultural values. As Coulo (2014) pointed out, science is not only guided by epistemic values but it is also affected by non-epistemic values because the ethical and political impact of scientific work and knowledge place responsibilities on scientists and scientific institutions.

Non-epistemic values obviously influence the external aspects of scientific inquiry. For example, ethical values may play an important role in the choice of research methods and treatment of research subjects (Coulo 2014). Also, scientists may choose to do certain kinds of

[1] Some criticize the epistemic/non-epistemic values distinction itself as untenable (Machamer and Douglas 1999; Rooney 1992). Our points can be made either way, so we choose to take the less controversial path of accepting the distinction, for present purposes.

research, but societies or institutions to which scientists belong may encourage or discourage them (Forge 2008, pp. 111–113). However, non-epistemic types of values also play a role in the internal aspects of scientific inquiry through the phenomenon of inductive risk, where the selection of standards in the trade-off between type I and type II error intersects with the consequences of error (Douglas 2000). Therefore, it is likely that non-epistemic values such as ethical and socio-cultural values may fundamentally influence the process and the content of scientific inquiry, as well as the application of scientific knowledge (Kelly et al. 1993). According to Allchin (1999), such value-ladenness can enhance the scientific endeavor because a diversity of values can promote robustness in knowledge and values can be objective through communal justification; value-ladenness can promote objectivity rather than violate it. Thus, we can expect that teaching the role of values in science can help students better understand how science really works. Teaching the role of values in science also can contribute to humanizing science and illustrating the ethical, cultural, and political facets of science (Matthews 1994, pp. 83 ff).

Learning science, however, does not automatically lead to informed public decision-making (Kelly et al. 1993). We posit that values can connect, rather than disconnect, scientific inquiry to decision-making if the role of values in science is properly understood. To this end, we focus our attention to John Dewey's theories of scientific inquiry and value judgment as an approach that can explain that connection. Dewey argues that inquiry and values are related and that value judgment can be improved through inquiry (Dewey 1948a, 1948b, p.174; Webster 2008). Science education owes a lot to John Dewey's ideas of how science should be viewed and what science education should do. Unfortunately, although Dewey's ideas have influenced every facet of progressive science education in the US, they have been underappreciated, misunderstood, and misapplied (Wong et al. 2001). It is worth returning to Dewey's theory of scientific inquiry in order to explore the relation between inquiry and decision-making. In this paper, we focus primarily on secondary science education in the US,[2] and explore how to help students use scientific inquiry in decision-making about socio-scientific issues based on John Dewey's theories of scientific inquiry and value judgment.

The argument of the article proceeds in two major stages. First, in Sections 2 and 3, we identify problems that arise in classroom cases and are present in educational standards. In Section 2, we examine several cases from previous studies showing how students used personal, social, and cultural values to make decisions about socio-scientific issues. In these cases, students made decisions about these issues based primarily on non-epistemic values and either did not rely on inquiry-based learning or cherry-picked scientific knowledge through the lens of personal, social, and cultural values. In Section 3, we cite several US science education standards documents to see how they present scientific inquiry, values, and decision-making. We focus on these standards documents because they are particularly problematic: the US standards set up expectations that inquiry-based learning in science will lead to improved decision-making without providing clear guidance about the relation between the two. Second, in Sections 4–6, we suggest solutions based on Dewey's theories to the problems presented by classroom cases and science education standards. In Section 4, we introduce how Dewey connected scientific inquiry, value judgment, and decision-making. We explain how Dewey's

[2] We focus in this way for several reasons: (1) narrowing the scope of consideration aids in brevity, keeping the argument more manageable; (2) science education and the role of science in contested public and political issues are particularly fraught in the US; and (3) it is the context we are most familiar with and most qualified to analyze. We include some non-US examples in Section 2, where doing so does not overly complicate the argument, but narrow our focus especially when considering science education standards.

ideas of inquiry and value judgment can connect scientific inquiry to decision-making in science education. In Section 5, we connect Dewey's ideas to contemporary philosophy of science, showing the mutual influence of values and science. Understanding this two-way interaction is a necessary part of scientific literacy and may make a significant impact on how students approach socio-scientific issues. In Section 6, we review the problems identified in Sections 2–3 and identify the solutions suggested by the theoretical frameworks discussed in Sections 4–5. Finally, in Section 7, we conclude by discussing some of the real-world implications of teaching values in scientific inquiry through socio-scientific issues.

2 Students' Uses of Values in Socio-Scientific Issues

We have reviewed a number of recent studies that investigate students' argumentation and decision-making about socio-scientific issues. These classroom cases indicate that students use non-epistemic values such as personal, social, and cultural values to make decisions about socio-scientific issues (Christenson et al. 2014; Evagorou et al. 2012; Grace and Ratcliffe 2002; Kolstø 2006; Lee 2007; Lindahl and Linder 2013; Nielsen 2012; Rundgren et al. 2016; Tal and Kemdi 2006). Using values cannot be a problem in informed decision-making; it is impossible to make rational, informed (as opposed to arbitrary) decisions without explicit or implicit reliance on values. We notice, however, a few potential problems with the way values and scientific evidence were integrated in students' decision-making processes. Thus, we closely examined several examples to see how students use values in their decision-making processes on socio-scientific issues and to determine what problems there are in those processes.

Evagorou et al. (2012) presented examples from the UK of how socio-cultural values affect students' decision-making in socio-scientific issues and of how little scientific inquiry actually contributes to students' decision-making. When two groups of students with different backgrounds, one with a high achieving white-British background and the other with a middle achieving Indian-British background, were asked to make a decision on a socio-scientific issue, their decisions appeared to be based on their cultural and social values rather than the inquiry conducted in their science class. The issue at hand in the study was the UK government's decision to cull the invasive gray squirrels to save the indigenous red squirrels; students were asked to make a decision about whether they agreed with the policy. According to Evagorou et al. (2012), there was no direct evidence supporting the claim that gray squirrels are responsible for the decline in the red squirrel population; therefore, the government's decision provoked several opposing arguments. Although both groups of students were taught about this issue using the same online inquiry-based learning environment, there was a clear difference between the groups in their decisions. A majority of students with a white-British background decided to kill the gray squirrels to save the red squirrels because, "[the grey squirrels are] *American … they are not native to Britain* and *they are taking over*" (Evagorou et al. 2012, p. 422, *emphasis in original*). Meanwhile, a majority of students with an Indian-British background decided to protect both the gray and the red squirrels because "it is inhuman/racist/illegal" (Evagorou et al. 2012, p. 416) to kill an animal. Students' explicit reasoning and the between-groups differences both suggest that the decisive factor for their evaluation was their values based on their socio-cultural context. Scientific information that students learned from the inquiry-based learning seems to have little effect over their decision-making.

Interestingly, students tended to accept evidence that supported their decision and to ignore contradicting evidence, suggesting that students' socio-cultural values became criteria to select scientific evidence (Evagorou et al. 2012). Kolstø (2006) reported a similar phenomenon in his study of students' reasoning about a controversial socio-scientific issue in Norway. The possible danger of increasing leukemia among the children who lived near the power lines due to the low intensity electromagnetic radiation from these power lines had been reported. Although there is not a scientific consensus yet in regard of this alleged danger, it ignited heated discussions to stop building such power lines. During the discussion about this issue, students showed five different types of arguments using values and scientific knowledge from a simple "small risk argument" saying that "risks are natural part of life" (Kolstø 2006, p. 1707) to a more advanced argument weighing the pros and cons in different consequences. In making arguments, students who had different values regarded different scientific knowledge as relevant. What kind of knowledge is considered relevant to make arguments depended on what students valued. In another study, Nielsen (2012) observed Danish upper-secondary biology students' socio-scientific discussions; this study showed that students take values as criteria to select and use scientific knowledge in making decisions, in ways that merely supported predetermined conclusions based on their values. In these cases, students co-opted science by cherry-picking scientific evidence to support their value-laden arguments. According to Levinson et al. (2012), science and mathematics teachers also show similar tendencies of co-opting scientific information in conjunction with their values to support a predetermined conclusion in risk-based decision-making.

Scientific inquiry that students conduct in the classroom may enhance their scientific knowledge related to socio-scientific issues, but it may have little effect on their ability to make informed decisions about those issues. Lee (2007) provided students with two inquiry-based learning experiences. First, students conducted scientific inquiry through simulation and experiments. They built a model of the human respiratory system to simulate smoking and tested the effect of smoking as well as the effect of second-hand smoking. Second, students conducted another inquiry to examine the effect of smoking using statistical analysis of public health data. Finally, students were asked to participate in discussion about the ban of smoking in all restaurants. The results showed that, even though students' knowledge related to smoking was improved through inquiry-based learning that consisted of simulation, experiment, and data analysis, many students' decisions were not consistent with evidence that they obtained in inquiry-based learning, but rather based on preconceived (unscientific) notions, and on economic values and values related to social status and cohesion. Lee (2007) suggested that a thorough understanding of the nature of scientific inquiry requires understanding the role of value judgment in science because values affect actions like weighing an argument and a counterargument, determining acceptable and unacceptable evidence, and deciding whether to accept and assert a hypothesis or not.

Values seem to be a dominant factor in students' decision-making regardless of their academic background, but these values are themselves hardly evaluated during the decision-making process. Christenson et al. (2014) reported a study of Swedish upper secondary students' argumentation and decision-making about socio-scientific issues such as global warming, genetically modified organisms, nuclear power, and consumer consumption. They compared social science major students and natural science major students. According to their results, students used non-epistemic values such as personal, social, and cultural values to develop arguments and make decisions, regardless of disciplinary background. Also, when students made arguments or decisions, they did not review science-specific or epistemic values such as objectivity, testability, and accuracy. Grace and Ratcliffe (2002) reported similar results in their study of students' decision-making discussions in two biological conservation scenarios. Although students used some biological concepts in their arguments, social or cultural values were the dominant decision-factors. In the study of Rundgren et al. (2016), science students from Swedish upper secondary schools participated in the socio-scientific discussion about environmental toxins in fish from the Baltic Sea. Students used the same information and agreed to scientific aspects of the issue. Nevertheless, they made decisions primarily on the basis of guiding beliefs arrived at intuitively and connected closely with their personal, social, or cultural values, and these values became the criteria to use scientific information as relevant evidence. During the discussion, students evaluated scientific knowledge and policy claims and counter-claims guided by their values, but they did not explicitly evaluate those values.

From these classroom cases, we found a few potential problems that obstruct students' informed decision-making. First, students' inquiry-based learning had little effect over their decision-making. For example, in Lee's (2007) study and in Evagorou et al.'s (2012) study, students learned scientific information related to the issue through the inquiry-based instruction. Nevertheless, students did not transfer those learning experiences to make informed decisions. Second, students rarely explored values involved in their decision-making over socio-scientific issues; rather, they dogmatically applied the values they already held. It also seems that students were not aware of the influence of their non-epistemic values when they used these values to make decisions. Third, without exploration or contemplation of values, there is a possibility that inappropriate or indefensible values are involved in students' decision-making. Students may use those values to select scientific evidence and to guide arguments. Considering these possible problems, we argue that students need to explore different values, epistemic *and* non-epistemic, embedded in socio-scientific decision-making to make informed decisions. Students also need to be consciously aware of their own personal, social, and cultural values when they make a decision in socio-scientific issues (Lee 2007; Wilkins 2017). Science education has to explicitly include value exploration in curriculum development, instructional design, and also in professional development programs for teachers (Allchin 1999; Levinson et al. 2012; Rundgren et al. 2016). The role of scientific inquiry in promoting a learner's capacity to make informed decisions also needs further exploration in science education.

3 A Missing Link Between Inquiry and Decision-Making in Science Education Standards

Achieving science literacy includes being capable of conducting scientific inquiry and making informed decisions about socio-scientific issues *based on a process of inquiry*. As Zeidler et al. (2005, p. 358) pointed out, many professional science organizations agree on the importance of inquiry and decision-making in science literacy.

> As the 21st century unfolds, professional associations (e.g., American Association for the Advancement of Science 1989, 1993; National Science Education Standards 1996; CMEC's Pan-Canadian Science Project 1997; Queensland School Curriculum Council 2001) in science recognize the importance of broadly conceptualizing scientific literacy to include informed decision making; the ability to analyze, synthesize, and evaluate information; dealing sensibly with moral reasoning and ethical issues; and understanding connections inherent among socioscientific issues (SSI) (Zeidler 2001).

McComas and Olson (1998) examined eight science education standards documents from the US, Canada, Australia, New Zealand, and England/Wales and showed that all these documents contain statements regarding scientific inquiry; understanding social, cultural, and historical aspects of science; and informed decision-making. Making an informed decision is also equally emphasized in two science education standards documents in the US, which were developed two decades apart:

> In a world filled with the products of scientific inquiry, scientific literacy has become a necessity for everyone. Everyone needs to use scientific information to make choices that arise everyday (NRC, *National Science Education Standards* 1996, p. 1).

> We believe that the education of the children of this nation is a vital national concern. The understanding of, and interest in, science and engineering that its citizens bring to bear in their personal and civic decision making is critical to good decisions about the nation's future (NRC, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas* 2012, viii).

The importance of making good decisions on the basis of scientific information, in both personal and civic contexts, is a long-running theme in science education standards worldwide, including standards in the US. We focus the rest of this article on the US context because it is a manageable scope for our analysis, because it is the context we are most familiar with, and because the US standards are particularly problematic in this area.

Inquiry is a core feature in science education and emphasized in many US science education standards including *National Science Education Standards* (NRC 1996), *Inquiry and the National Science Education Standards* (NRC 2000), and *Benchmarks for Science Literacy* (AAAS 1993). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas* (NRC 2012) and the *Next Generation Science Standards* (NGSS Lead States 2013) also emphasize inquiry through a scientific and engineering practices dimension. The term *inquiry* is used in two different ways in science education. First, it refers to the abilities and understanding students should develop to be able to conduct scientific investigations, and second, it refers to the teaching and learning strategies (NRC 2000, p. 13). If inquiry refers to the teaching and learning strategies, then inquiry can be used to learn how to make informed decisions.

How inquiry helps students learn to make informed decisions, however, is not clearly explained in these science education standards. Instead, *Benchmarks for Science Literacy* (AAAS 1993) mentions critical response skills that students need to learn to make judgments based on their scientific knowledge:

> Apart from what they know about the substance of an assertion, individuals who are science literate can make some judgments based on its character. The use or misuse of supporting evidence, the language used, and the logic of the argument presented are important considerations in judging how seriously to take some claim or proposition. These critical response skills can be learned and with practice can become a lifelong habit of mind (AAAS 1993, p.298).

Learning critical response skills is not, however, enough for students to learn informed decision-making. First, critical response skills are useful for making judgments about whether or not to accept a factual claim, and decision-making requires more than factual claims. Values are involved in making every decision. Without considering values, accepting a certain factual claim does not automatically justify a decision. Second, the critical response skills mentioned in the standards are skills to judge a given claim, not skills to use or learn to engage in inquiry. Therefore, the link that describes a relationship between scientific inquiry and decision-making is missing in science education standards. Science education standards provide the basis to develop curriculum, instructional designs, teaching strategies, and assessment. The missing link in science education standards indicates that we cannot find the basis for teaching how scientific inquiry helps students make informed decisions in these science education standards.

To restore the link between scientific inquiry and decision-making, we turned our attention to John Dewey, the founding thinker of inquiry-based education and a philosopher of science with a keen interest in the relationship between science and values. In the next section, we explore the relationship between scientific inquiry and decision-making based on Dewey's views of the relationship among scientific inquiry, value judgment in science, and decision-making.

4 Scientific Inquiry, Value Judgment, and Decision-Making

Scientific inquiry and its contribution to society play a central role in the philosophical and educational work of John Dewey. Dewey (1910/1995) emphasized that science is not only a body of subject-matters and results but also a process or method and an attitude. He pointed out that science education focused too much on teaching a body of ready-made knowledge and not enough on inculcating a method of thinking—in other words, scientific inquiry (Dewey 1910/1995). For Dewey, the primary goal of science education is to develop students' ability to inquire as a habit of mind. Dewey's emphasis on scientific inquiry is similar to the emphasis made in *Benchmarks for Science Literacy* (AAAS 1993), *National Science Education Standards* (NRC 1996), and *A Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas* (NRC 2012). Today, the major goal of science education is for students to achieve science literacy, and scientifically literate people are expected to be able to make informed decisions about socio-scientific issues that they face in their lives (AAAS 1993, p. 322; NRC 1996, p. 22; Rutherford and Ahlgren 1990, p. x). Thus, whether experiences of conducting scientific inquiry can help students in making informed decisions will be the important question to explore.

As seen in the previous section, science education standards assume but do not explain how conducting scientific inquiry helps students make informed decisions, leaving it as a missing link. Decision-making requires value judgment. In particular, when students deal with socio-scientific issues, high-order thinking skill for reasoning and value judgment are essential factors to make informed decisions (Tal and Kemdi 2006). If we can explain how scientific inquiry and value judgment are related, we might be able to explain how scientific inquiry and decision-making are related. Then the question that we need to explore is what kind of relationship there is between scientific inquiry and value judgment. *Science for All Americans* described scientific inquiry, values, and attitudes as habits of mind (Rutherford and Ahlgren 1990, pp. 172–175). Although these concepts were considered essential, they were only presented in a way that juxtaposed them as separate and independent factors. What seems to be forgotten here is the connection between scientific inquiry and value judgment (see Fig. 1) and we could not find an answer to this hidden connection in the science education standards. This is the place that John Dewey's idea of scientific inquiry and of the relationship between inquiry and values can be used to explain this invisible connection.

According to John Dewey, the uses of scientific inquiry can improve students' ability to make value judgment (Webster 2008). Inquiry and values are not separate but related because the direction taken by inquiry is under the influence of values (Dewey 1948a). Thus, in science, inquiry should not be guided by inappropriate, external interests as Dewey explained:

> The actual course of scientific inquiry has shown that the best interests of human living in general, as well as those of scientific inquiry in particular, are best served by keeping such inquiry "pure" from interests that would bend the conduct of inquiry to serve concerns alien to conduct of knowing as its own end and proper terminus (Dewey 1948a, p. 206).

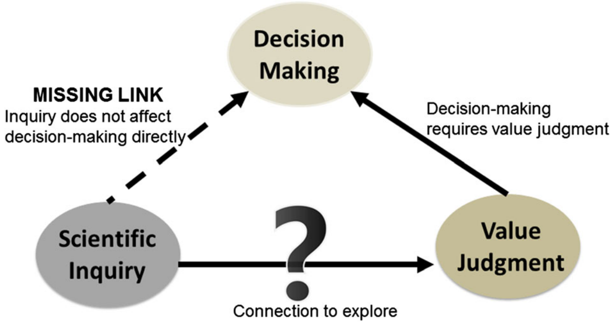

Fig. 1 The incomplete connections among scientific inquiry, value judgment, and decision-making

Pure inquiry does not mean value-free ideal in scientific inquiry. Rather, it means that when scientific inquiry is not misguided by inappropriate interests, it works based on evidence-based thinking, critical thinking, and open evaluation, and eventually, it can contribute to make judgments as intelligent as possible (Dewey 1910/1995; Webster 2008). The inappropriate, external interests, the "concerns alien to conduct of knowing as its own end and proper terminus," (Dewey 1948a, p. 206) are not all non-epistemic values, but rather, those values arrived at prior to and dogmatically held independently of scientific inquiry.

Dewey (1910/1995) warned that if science succumbed to *inappropriate*, external interests, it is no longer able to contribute to social and moral ideals, and further, to democracy.

> The modern warship seems symbolic of the present position of science in life and education. The warship could not exist were it not for science: mathematics, mechanics, chemistry, electricity supply, the technique of its construction and management. But the aims, the ideals in whose service this marvelous technique is displayed are survivals of a pre-scientific age, that is, of barbarism. Science has as yet had next to nothing to do with forming the social and moral ideals for the sake of which she is used (Dewey 1910/1995, p. 397).

Note how orthogonal Dewey's concerns are to the ideal of value-free science. Presumably, the science and engineering that produce the modern warship are not, by dint of the values involved, less objective, or somehow epistemically objectionable. But even though the warship *works* perfectly well, and we know it to be so, the role of values in these scientific inquiries is highly problematic. The military interests behind the warship are precisely the kind of inappropriate, dogmatic, pre-scientific values that Dewey hopes to keep out of science, in favor of values produced or tested in the course of scientific inquiry. In fact, when scientific inquiry keeps out of such inappropriate values "that would bend the conduct of inquiry to serve concerns alien to conduct of knowing as its own end… (Dewey 1948a, p. 206)," scientific inquiry can contribute to social and moral ideals (Dewey 1910/1995). Therefore, Dewey argued that science should focus on what we should do, and not merely on how we would do it (Dewey 1910/1995).

Thinking about what we should do indicates value-laden thinking. So Dewey's argument implies that scientific inquiry is a value-laden practice, so that engaging in *pure* scientific inquiry should include making good value judgments. According to Dewey, the term *value* has two meanings: *valuing*—the attitude of appreciating, esteeming, or prizing; and *evaluation*—the intellectual act of comparing, appraising, estimating, and judging (Dewey 1916a; 1916b, chapter 18, section 2). As a value-laden practice, scientific inquiry includes acts of comparing and judging multiple competing values. The involvement of alternative values in scientific inquiry does not weaken the objectivity of science. Rather, it can enhance objectivity by exposing error or deepening interpretative objectivity (Allchin 1999). Good value judgment, based on reflective, deliberate value judgment, helps enhance objectivity and produce reliable knowledge. Figure 2 shows the relationship among scientific inquiry, value judgment, and decision-making based on Dewey's view. At the bottom of the triangle shape, there is an arrow from value judgment to scientific inquiry. This arrow represents that values are involved in conducting scientific inquiry, which thus is a value-laden activity. There is another arrow from scientific inquiry to value judgment. This arrow represents that students can improve their value judgment through scientific inquiry—for example, by learning about the connections between means and ends or about the factual presuppositions of values. These two arrows represent mutual connection between scientific inquiry and value judgment that is Dewey's idea of scientific inquiry and of the relationship between inquiry and values. Based on Dewey's view, we can see now how scientific inquiry can contribute to informed decision-making. Decisions require value judgment. Scientific inquiry can improve our ability to make value judgments. Therefore, scientific inquiry can contribute to make better-informed decisions.

5 Practical Value Judgment in Scientific Inquiry

The next question to explore will be how scientific inquiry can improve value judgment. If scientific inquiry can improve value judgment, we need to know how it happens and how to apply this knowledge to science education. Dewey argued that "enforcing obedience to precepts does not do any good because it cut off the possibility of learning better ways to live by experimenting with them" (Anderson 2014, section 2). Sometimes certain values are presented to students as scientific values in the science classroom. Other times the idea that science is value-free or value-neutral is implicitly accepted among students as a precept. Considering Dewey's argument, however, it would not be appropriate to ask students to accept certain values as precepts when they conduct scientific inquiry because it will take away the opportunity to experiment with various values. Nor should students be asked simply to bring the values they have learned elsewhere (e.g., home, church) to bear on socio-scientific issues. Several previous studies have shown that students often bring personal, social, or cultural values they learned elsewhere to make a decision in socio-scientific issues (Christenson et al. 2014; Evagorou et al. 2012; Grace and Ratcliffe 2002; Kolstø 2006; Lee 2007; Rundgren et al. 2016). Students need to know that various values can be involved during the inquiry, and

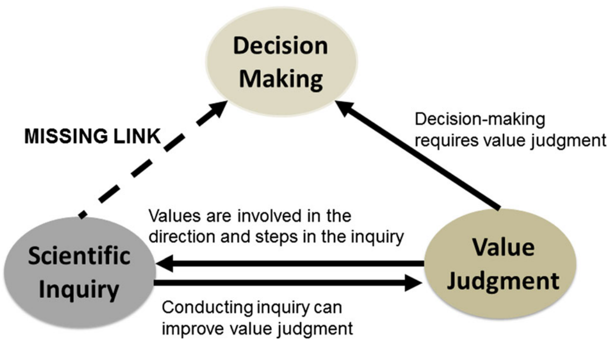

Fig. 2 The completed connection between scientific inquiry and value judgment by Dewey's view

science education should provide an opportunity for students to conduct inquiries that include value judgment (Allchin 1999; Wilkins 2017).

Dewey suggested that a judgment of value is actually a species of practical judgment, “a judgment about the doing of something” (Dewey 1916a/2004, p. 229):

> A practical judgment has been defined as a judgment of what to do, or what is to be done: a judgment respecting the future termination of an incomplete and in so far indeterminate situation. To say that judgments of value fall within this field is to say two things: one, that the judgment of value is never complete in itself, but always in behalf of determining what is to be done; the other, that judgments of values (as distinct from the direct experience of something as good) imply that value is not anything previously given, but is something to be given by future action, itself conditioned upon (varying with) the judgment (Dewey 1916a/2004, p. 230).[3]

The value judgment that students make during scientific inquiry is also a practical judgment because, at each step of the inquiry, students need to decide what to do or what is to be done, and values related in that situation will influence the decision. According to Dewey (1916a/2004), value judgment can be empirically tested (see Anderson 2014, especially section 2.4). When students make a value judgment to guide their action, there will be consequences of that particular action, and these consequences will help determine if that value judgment was correct or not. If students are aware of the function of value judgments in guiding action, they can evaluate their value judgments by evaluating the consequences of the action. For example, in the study of Evagorou et al. (2012), if students had evaluated their collected information and had realized that they gathered only one-sided information, such as government-issued reports or only information about red squirrels but not about gray squirrels, they could also evaluate their value judgment. Their social or cultural values may have guided their search for information, resulted in collecting incomplete, biased, one-sided data. The way that their previously held values tended to mislead their data collection should lead them to question the way that they made value judgments in the course of that inquiry. Thus, students’ value judgments can be empirically tested while they are conducting scientific inquiry. In this way, the uses of scientific inquiry can improve students’ ability to make value judgments (Webster 2008). That these are improvements to value judgments is clear only if we follow Dewey in thinking of value judgment as primarily concerned with actions (in this case, the action of collecting data to support informed civic decision-making).

Practicing value judgments and making good value judgments can also enhance the process of scientific inquiry. Value judgment, as a part of practical judgment, will be made during the whole process of scientific inquiry. Every time a student decides what to do, values will be involved, whether it is about selecting a particular method, collecting data, or interpreting the results.[4] Often, non-epistemic values such as ethical, social, and cultural values are considered

[3] Indeed, Dewey defined his version of pragmatism as the hypothesis that *all* judgments, including both judgments of value and judgments of fact, are at bottom *practical judgments* in this sense. On this view, “all categorical propositions,” whether propositions of fact or of value, “would be hypothetical, and their truth would coincide with their tested consequences effected by intelligent action” (Dewey 1916a/2004, p. 222). Some might conclude thus that Dewey’s understanding of value judgment invalidates our discussion of values as a *factor* in practical judgment and of the *role* of values in science. To the contrary, Dewey could still make *functional* distinctions between types of judgment; his point was that all these types of judgment share the same logical form and truth conditions, not that it is impossible to many any distinction between them, nor say anything interesting about the functional relations between them. Indeed, replacing absolute distinctions with functional ones is at the core of Dewey’s philosophical project. Thus, it remains sensible and necessary to distinction value judgments from more *immediate* decisions about what to do (see Dewey 1938, Chapter 4; Dewey 1948a).

[4] Following Dewey, every time a student makes a value judgment, a question of what is to be done is involved. Value judgments are not given prior to inquiry, but are made as part of inquiry.

to only affect external part of science practice, for example, "the selection of hypotheses, restrictions on methodologies, and the use of scientific technologies" (Douglas 2000, p. 559). These values, however, can also affect the internal part of science practice such as statistical significance, evidence characterization, and interpretation of the results (see Douglas 2000, pp. 569–572 for examples); one reason this is so is due to considerations of inductive risk, that is, the consequences associated with the inevitable error in inductive or ampliative inference (Rudner 1953; Hempel 1965; Douglas 2000, 2009). This is how authentic science works, with values affecting both external part and internal part of scientific inquiry. Science education aims to teach how science works, so that including value judgment in scientific inquiry is inevitable.

Social, ethical, or cultural values can influence the selection of hypotheses because these values inform certain hypotheses or make it difficult to accept hypotheses that contradict these values, as was seen in the resistance to Heliocentrism in the Copernican Revolution. *Benchmarks of Science Literacy* (AAAS 1993) suggest open-mindedness with skepticism as an important habit of mind in doing science, but it is not easy to have such an attitude because open-mindedness toward a new idea and skepticism against it can create a tension. Such an intrinsic tension is, in fact, unavoidable in doing science so that practicing how to balance between open-mindedness and skepticism is essential in learning science. Taking values into account when selecting hypotheses can provide students with a good opportunity to practice balancing open-mindedness with skepticism. Values can also influence methodological choices. Exploring the relevant values and making value judgments can reduce the chances of choosing methodological options with ethically unacceptable consequences, e.g., with respect to the treatment of human or animal research subjects. Value judgment can also help in evidence characterization, when deciding how to characterize ambiguous data. Questioning and challenging values that might be involved in evidence characterization may help reduce the harmful consequences of possible errors in dealing with ambiguous data. For instance, Douglas (2000) described a case where different groups of scientists evaluated the same rat-liver slides for the presence of tumors in significantly different ways, and she argued that each group was tacitly applying different values (pp. 569–572).

Value judgment can also help in the interpretation of the results. This is the core issue of inductive risk. When deciding whether the data that has been gathered is sufficient to support a particular hypothesis, one is likely to commit one of two types of error. False-positive error involves accepting a hypothesis when it is, in fact, false. False-negative error involves rejecting (or withholding acceptance from) a hypothesis when it is, in fact, true. These errors trade off against each another,[5] and committing different errors can have different kinds of consequences. To decide how to interpret results, therefore, one must make value judgments about the standards of evidence and tolerable levels of error (Douglas 2000, 2009).

6 Connecting Inquiry and Values in the Science Classroom

In the previous sections, we explained that there is a missing link in several science education standards about how scientific inquiry can help make informed decisions. We relied on Dewey's philosophy that scientific inquiry and value judgment are closely related to connect

[5] One can minimize both types of error as effect size increases, or by gathering larger quantities of data, but once these factors are fixed, the trade-off is pretty much direct.

that missing link. Relating inquiry and values, however, is not unfamiliar idea in science education because *Science for All Americans* (Rutherford and Ahlgren 1990) already recognized the interaction between values and science.

> Throughout history, people have concerned themselves with the transmission of shared values, attitudes, and skills from one generation to the next. Even today, it is evident that family, religion, peers, books, news and entertainment media, and general life experiences are the chief influences in shaping people's views of knowledge, learning, and other aspects of life. Science, mathematics, and technology can also play a key role in the process, for they are built upon a distinctive set of values, they reflect and respond to *the values of society generally*, and they are increasingly influential in *shaping shared cultural values*. Thus, to the degree that schooling concerns itself with values and attitudes, it must take scientific values and attitudes into account when preparing young people for life beyond school (Rutherford and Ahlgren 1990, p. 171, *emphasis added*).

This recognition, however, faded away in *Benchmarks of Science Literacy* (AAAS 1993) the following publication after *Science for All Americans* (Rutherford and Ahlgren 1990). *Benchmarks of Science Literacy* (AAAS 1993) suggested practical standards for different age groups under the concepts and ideas from *Science for All Americans* (Rutherford and Ahlgren 1990). There, honesty, curiosity, and balancing open-mindness with skepticism were suggested as scientific values that students should know.

> Honesty is a desirable habit of mind not unique to people who practice science, mathematics, and technology… Curiosity does not have to be taught. The problem is the reverse: how to avoid squelching curiosity while helping students focus it productively… [and] Balancing open-mindness with skepticism may be difficult for students (AAAS 1993, p. 284).

These are descriptions of epistemic values or epistemic virtues shared in science domain, not explanations of how values and science are related. The relationship between values and science was thus introduced once, but was not pursued further, particularly not to the point of teaching value judgment as part of inquiry. Instead, students were asked to accept values like honesty, curiosity, and balancing open-mindness with skepticism as precepts. As Dewey pointed out, demanding compliance with precepts, without opportunities to examine and test them, is "a formula for perpetual immaturity" (Anderson 2014, section 2). Instead of introducing "scientific values" as precepts, scientific inquiry should provide both intellectual and methodological means to critically evaluate various values (Dewey 1916a/2004; Anderson 2014; Rutherford and Ahlgren 1990).

Teaching value-laden inquiry in the science classroom may be difficult if there is not an explicit guidance in science education standards. Science education standards provide the basis for preparing curriculum and instruction. Without explicit statements in the standards, alternative explanations about how to connect inquiry and values may be necessary, at least in the US context. Table 1 summarizes these alternative explanations. It shows a few problems that we recognized in science education standards including *Benchmarks for Science Literacy* (AAAS 1993), *National Science Education Standards* (NRC 1996), and *A Framework for K-12 Science Education: Practices, Crosscutting Concepts and Core Ideas* (NRC 2012), and cases of students' uses of values in decision-making. The missing link between inquiry and decision-making indicates that we lack an account of how scientific inquiry can help make scientifically informed decisions. One way to solve this problem is to explore the relationship between inquiry and values in science because decision-making requires value judgment. The connection between inquiry and values in science, however, is also missing from science education standards, either because they are committed to the value-free ideal, according to which values are not supposed to be explored during scientific inquiry, or simply because they provide no guidance for connecting inquiry and values in science education. Table 1 also

Table 1 Problems found in science education and solutions based on Dewey's view

Problems in current science education	Solutions based on Dewey's view
Conducting inquiry does not automatically help in making an informed decision.	Decision making requires value judgment, and inquiry can improve value judgment. If conducting scientific inquiry includes improving value judgments, it can lead to scientifically informed decision making.
Inquiry and values in science are not explicitly connected.	Every decision-point in scientific inquiry, external or internal, potentially requires value judgment in order to make judgments about how to proceed. Inquiry essentially involves practical value judgment.
Values are provided as precepts and not explored during inquiry.	Making a practical judgment during the scientific inquiry gives students an opportunity to critically evaluate various values and apply them. At each step of the inquiry, students will decide what to do after evaluating the values involved.

shows possible solutions to these problems, based on Dewey's view. According to Dewey (1916a/2004, 1948a), scientific inquiry should include good value judgments, and a value judgment in scientific inquiry is a practical judgment to guide an action which result reflects involved values. Thus, conducting scientific inquiry can improve students' ability to make good value judgments (Webster 2008).

Values in science are mostly introduced with socio-scientific issues in middle school and high school classrooms. Socio-scientific issues that are relevant for students' moral, ethical, and epistemological development can contribute to the development of making informed decisions (Zeidler et al. 2005). As seen in the classroom cases from previous studies, socio-scientific issues in secondary education were mostly taught through discussions. In students' discussions, socio-scientific issues often turned into moral issues and were influenced by social or cultural values (Sadler and Zeidler 2004). Dewey's views implied an alternative way to explore values through inquiry in science classroom. Inquiry-based learning such as simulation, experiment, and observation to learn scientific knowledge that is related to the socio-scientific issue can be planned ahead of students' discussion (Lee 2007). In such inquiry-based learning, opportunities to explicitly consider value judgments should be included, so that students can develop reasoning based on both scientific knowledge and values. Students can depend on that reasoning when they make a decision over a socio-scientific issue. They should also learn several things about values when they conduct inquiry in the science classroom. First, students should know that various values are involved in the scientific inquiry, and those values can be challenged and evaluated (Allchin 1999; Lee 2007; Wilkins 2017). Second, they should know that they are making practical value judgments at every decision-point in scientific inquiry, and they can evaluate the involved values by examining the result of an action on the basis of those value judgments (Anderson 2014; Dewey 1916a/2004, Tal and Kemdi 2006). Third, students should know that conducting scientific inquiry needs to include a good value judgment (Allchin 1999; Tal and Kemdi 2006; Webster 2008). Then, inquiry and values can be connected in students' minds through the classroom activity.

7 Conclusion and Educational Implications

A scientifically literate person is expected to be able to make informed decisions based on inquiry. We focused on secondary science education in the US and explored how science education can help students use inquiry to make informed decisions about socio-scientific issues. We examined several US science education standards and found that these standards do not explicitly provide an explanation of how scientific inquiry can contribute to informed decision-making. Previous studies of secondary school age students' decision-making in socio-scientific issues showed that students made decisions using values, but values were not explored—in John Dewey's terms, students' decisions reflected their *valuing*, but students did not engage in *evaluation*. Dewey's view that the use of scientific inquiry can improve students' value judgment provides the link between inquiry and decision-making. Also, Dewey's theory that value judgment is a practical judgment aimed at guiding action provides the basis to explore various values in scientific inquiry. Students can explore values during scientific inquiry by making practical value judgments, and students' experience of making good value judgment can contribute to make informed decisions.

Dewey's views also provide an alternative way to teach socio-scientific issues in science classroom. Lessons based on socio-scientific issues can be useful to practice informed decision-making, and those issues are usually taught in the form of student discussions. Taking Dewey's views, however, teachers can engage students in inquiry-based learning to teach socio-scientific issues. During inquiry, students can learn scientific knowledge that is related to the socio-scientific issue and practice value judgment. Students can also develop arguments or make decisions based on their inquiry and value judgment. For many science teachers, this is not a familiar way to teach socio-scientific issues. Thus, professional development programs and teacher education programs to prepare teachers are necessary for classroom application of this approach. These programs need to provide teachers with two types of experience. One of them is for teachers to experience inquiry-based, value-judging exploration of socio-scientific issues. The other is for teachers to practice how to plan and implement inquiry-based teaching of socio-scientific issues in the classroom. The development of various inquiry-based socio-scientific teaching resources is also essential for classroom application and requires continuous attention from science educators.

Acknowledgements This material is based upon work supported by the National Science Foundation under grant no. 1338735. Our thanks to Magda Grohman, Nick Gans, Marco Tacca, the members of the Values in Science Research Lab, and the audience at the Philosophy of Science Association.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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