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Abstract

We propose two contrasting types of student decision-making based on social and cognitive psychology models of separate mental processes for problem solving. Informal decision-making uses intuitive reasoning and is subject to cognitive biases, whereas formal decision-making uses effortful, logical reasoning. We explored indicators of students' formal decision-making in a socioscientific issue-focused general science post-secondary course that used a seven-step decision-making framework based in decision-science models. We found that students' value orientations predicted students' stance towards biofuels at the beginning but not at the end of the course, indicating some students' post-survey opinions were less rooted in affective value-judgments. Themes in student personal reasoning about biofuels were primarily focused on environmental and economic dimensions of the issue and revealed a greater awareness of alternative options and potential consequences of biofuel use at the end of the course. We observed a decrease in students' emotive arguments and an increase in students' justificatory arguments about biofuel use. A formal decision-making framework may be a useful tool in supporting students' formal, reasoned approach to deciding what we should do about complex socioscientific issues.

Introduction

Science education plays an key role supporting science literacy, or in other words, helping students not only understand science content, but also in developing skills required for personal decision-making, participation in civic and cultural affairs, and economic productivity (National Research Council, 1996). The need to emphasize decision-making as part of science education has long been noted by the scientific community, such as the Association for the Advancement of Science (Rutherford & Ahlgren, 1989) and the National Research Council (National Research Council, 1996), as well as by science educators themselves (Aikenhead, 1985; Kolstø, 2006; Millar & Osborne, 1998; Zeidler, Sadler, Simmons, & Howes, 2005). As tomorrow's voters, workers, policymakers, and consumers, postsecondary students – both STEM and non-STEM majors – must be prepared to examine complex socioscientific issues (SSIs) and make socially responsible, science-informed decisions about them. Institutions of higher education have a responsibility to prepare students for all facets of life, help them master "21st Century Skills," such as integrating knowledge and decision-making, and develop science literacy throughout their lives (Pellegrino, Hilton, & others, 2013).

We propose two types of SSI decision-making that are based on dual-process models in social and cognitive psychology that separate intuitive, effortless mental processes from logical, effortful mental processes (Kahneman, 2011; Peters & Slovic, 2000; Smith & DeCoster, 2000). The first type of decision-making in which students may engage can be considered *informal* decision-making. Student reasoning about SSIs in general has been characterized as "informal reasoning" that includes a combination of forms including rationalistic, emotive and intuitive reasoning (Sadler, Chambers, & Zeidler, 2004; Sadler & Zeidler, 2005a, 2005b). Likewise, informal decision-making also relies on intuitive and cognitive pathways of reasoning, and individuals successfully use this system in thousands of decisions that are made on a daily basis (Kahneman, 2011). However, individuals applying informal decision-making to issues that are complex and ill-structured such as SSIs may neglect to consider all relevant values, scientific information, solutions, and tradeoffs (Arvai, Campbell, Baird, & Rivers, 2004). These suboptimal decision-making process occurs because individuals sometimes rely on simple heuristics to make judgments and decisions (Gregory, Failing, Harstone, Long, McDaniels, & Ohlson, 2012; Kahneman, 2011). Heuristics are simple decision rules that are essentially short cuts to help an individual avoid deliberation, e.g., “If my parent vote ‘yes,’ than I will too.” Some heuristics arise when individuals rely on limited amounts of information or focus on affect or a single value, and often these heuristics result in cognitive biases (Arvai et al., 2004).

Previous research on undergraduate students’ decision-making about SSIs illustrates challenges that students face when engaging in informal decision-making in a classroom setting. These challenges include struggling to evaluate advantages and disadvantages of alternative outcomes and reflect on choices (Grace, 2009), lacking specificity when weighing tradeoffs (Eggert & Bögeholz, 2009; Jiménez-Aleixandre, 2002; Seethaler & Linn, 2004), emphasizing values at the expense of seeking additional scientific information that would clarify different choices (Grace & Ratcliffe, 2002; Hong & Chang, 2004; Sadler, 2004), and difficulty integrating knowledge gained in science with real-world problems (Kolstø, 2006). Students need support and practice using formal and logical pathways of thinking to develop decision-making skills. Science classrooms are an opportunity for developing these practices (Covitt, Harris, & Anderson, 2013) and science instructors are uniquely positioned to help students reason through a problem, apply scientific evidence, and thoroughly examine their values and potential choices.

In contrast to informal decision-making, *formal* decision-making involves a more thorough and cognitively challenging examination of multiple values, rather than initial affective impressions, and would employ scientific information (including examining uncertainty and risk), to inform value-tradeoffs between multiple potential solutions (Gregory et al., 2012; Hammond, Keeney, & Raiffa, 2015; Wilson, 2008). Formal ways of thinking about SSIs involve being deliberate, rational, and paying attention to uncertainties (Kahneman, 2011; Kahneman, Slovic, Tversky, & others, 1982). Classrooms can support formal decision-making by making students aware of common psychological traps that can bias decisions and by teaching specific skills for incorporating both personal values and technical information into decision-making (Arvai et al., 2004). Several science education researchers have provided various tools, frameworks or steps for supporting formal decision-making in classroom settings (Aikenhead, 1985; Edelson, Tarnoff, Schwille, Bruozas, & Switzer, 2006; Kolstø, 2000; Siegel, 2006). However, tools grounded in the decision sciences specifically provide decision support that is designed to avoid cognitive biases and heuristics (Hammond et al., 2015), which could be applied to classroom settings to scaffold students’ learning and encourage more sophisticated decision-making.

We developed a unique undergraduate general sciences course that supports student decision-making about challenging real-world issues (Dauer & Forbes, 2016). In the course students are asked to choose solutions to a problem using a formal scaffolding process that makes multiple potential options, scientific information and values explicit. We ask students to use a seven-step decision-making framework (adapted from Ratcliffe, 1997) based on normative and descriptive decision-making models (Grace, 2009). The purpose of this scaffolding was to support students’ ability to be specific about weighing tradeoffs, integrating scientific information into their analysis of potential solutions, and being clear about the separate and important roles of scientific information and personal values. Ultimately, we hope that decision-making practices learned in the context of our course transfer to everyday life practices. Transfer is the ability to apply a newly gained skill to a new context (Bransford & Schwartz, 1999), and one indicator that transfer has occurred is the presence higher quality reasoning at the end of the course without decision-making scaffolding. Therefore, in this study we investigated if students’ classroom experiences practicing the scaffolded seven decision-making steps transferred to their unscaffolded personal reasoning about how a controversy revolving around an SSI should be resolved.

Biofuels as a Socioscientific Issue

A crucial issue for our global future is the development and adoption of alternative energy sources such as biofuels. In particular, biofuel technology is an important frontier for energy use under the specter of global climate change. Students as citizens will need to make informed and responsible decisions about sources of energy that will reduce human contribution to greenhouse gas emissions. To make evidence-based decisions about biofuels, students will need specific scientific knowledge about matter and energy in processes like photosynthesis, cellular respiration and combustion that are often challenging (Parker, de los Santos, Anderson 2015). Additionally, students will need to weigh and leverage economic, environmental and social values along with scientific information to navigate decision about biofuel technology (Price, Walker, & Boschetti, 2014). These factors make biofuels a significant, timely and complex SSI requiring multidisciplinary learning.

Notably, the scientific community is currently debating the utility of biofuels in reducing greenhouse gases and dependency on fossil fuels. Currently the large majority of biofuels used in the United States is ethanol from corn. Of the biofuels used in the U.S. in 2012, 94% is corn ethanol and the remaining 6% is chiefly soy biodiesel ("USDA ERS - U.S. Bioenergy Statistics," 2016). Life cycle analyses report modest gains in carbon emissions using corn ethanol over petroleum-based fuels (Liska, Yang, Bremer, Klopfenstein, Walters, Erickson, & Cassman, 2009; Wang, Han, Haq, Tyner, Wu, & Elgowainy, 2011). The gains diminish when estimates of indirect land use change, which are highly variable, are included in the life cycle analysis (Fargione, Hill, Tilman, Polasky, & Hawthorne, 2008; Plevin, Jones, Torn, & Gibbs, 2010; Searchinger, Heimlich, Houghton, Dong, Elobeid, Fabiosa, Tokogoz, Hayes & Yu, 2008). Gains are also variable depending on soil management and biorefinery efficiency (Liska, et al., 2009). Because production of corn ethanol requires fossil fuels and depends on soil quality and water availability, some argue that corn ethanol is unsustainable and impractical in the long-term. Considering agricultural impacts on water quality, soil conservation and biodiversity (Joly, Huntley, Dale, Mace, Muok, & Ravindranath, 2015; Wiens, Fargione, & Hill, 2011), it is debatable if biofuels are "better for the environment" than fossil fuels. Given the ongoing debate and lack of consensus among scientific communities, much of the environmental and economic impact of biofuels can be considered "frontier science" (Kolstø, 2001). These qualities—challenging biology, ecology and earth science content and uncertainty in scientific information—make biofuels a particularly interesting SSI for classrooms.

Objectives

The first goal of this paper is to explore how students' values play a role in their thinking about biofuels. In structured decision-making models, informed decisions *should* be made based on values, but with reasoned logic that weighs tradeoffs and is attentive to how scientific information predicts the performance of each choice (Gregory et al., 2012; Hammond et al., 2015). Theories that predict pro-environmental behavior point to values as ultimate drivers of policy support or action (Stern, 2000; Vaske, Manfredo, Decker, Riley, & Siemer, 2012). Understanding the complex relationship between students' values and the lens by which they view SSI's can be valuable in informing instruction. To investigate student values, we measured value orientations and tested their relationship to students' position on biofuels measured before and after the class. While values are stable guiding principles in one's life of which there are few across cultures, (Schwartz, 1992) value orientations are dimensions upon which related values cluster and predict general and specific beliefs (De Groot & Steg, 2008). The value orientations we used are based on the Value-Belief-Norm (VBN) Theory (Stern, 2000), where individuals are aligned along three set of beliefs regarding human-nature relationships (i.e., altruistic, biospheric, egoistic; Stern 2000). Egoistic values reflect self-enhancement while altruistic values reflect self-transcendence; biospheric values focus on social goods related specifically to the environment (Stern, 2000). VBN Theory has been widely used to understand environmentally significant decision-making and predict behaviors relevant to diverse environmental contexts (e.g., recycling) and across cultures (Huffman, Van Der Werff, Henning, & Watrous-Rodriguez, 2014; Sussman, Lavallee, & Gifford, 2016). VBN Theory has not been applied to educational settings other than cross-cultural comparisons (Cordano, Welcomer, Scherer, Pradenas, & Parada, 2010; Menzel & Bögeholz, 2010) and evaluation of study abroad (Wynveen, Kyle, & Tarrant, 2011), despite being potentially useful lens for understanding values that students leverage in informal reasoning about SSIs.

According to VBN Theory, there is a causal chain that moves from relatively stable, central elements of values, to beliefs and personal norms and then to behavior (Stern, 2000). Each variable in the chain directly affects the next and may also affect variables further down the chain. We propose that value orientations are most closely aligned with individuals' initial affective impressions of an issue, and hence are a better predictor of individuals' stances toward an issue when informal decision-making is engaged. Others have noted the difference between individuals' initial "value-judgments" and reasoned values-based decisions. For example, Wilson and Arvai (2006) found that participants in an experiment were unable to stay focused on stated conservation values (objectives) that were intended for a formal decision-making process, and ultimately, participants made decisions that reflected their initial affective impressions that aligned with informal mental processes (Wilson, 2008). In contrast, formal decision-making is rooted in internal consistency between a suite of values and a reasoned analysis of tradeoffs instead of being rooted in affective impressions. In formal decision-making, the causal chain between values, beliefs and norms is somewhat altered by individuals' new reasoned analysis, so value orientations may be less strong of a predictor of decisions. Therefore our first research question is: do value orientations predict students' position on the biofuels issue before or after the course?

A second goal for this paper is to describe student thinking about biofuels as a controversial SSI. Remarkably few studies in science education have documented student knowledge or informal decision-making about biofuels. Parker, de los Santos and Anderson (2015) describe how students' challenges with tracing matter and energy through carbon-transforming processes may impede student understanding of biofuels since these difficult concepts are at the center of analyses of the performance of biofuels. Other science education literature has described techniques for using biofuel technology in a laboratory setting (Blatti & Burkart, 2012; El Seoud, Loffredo, Galgano, Sato, & Reichardt, 2011; Wagner, Koehle, Moyle, & Lambert, 2010). Themes emerging from students' positions on biofuels may reveal gaps in understanding about scientific, social, and economic dimensions of the issue. Identifying such knowledge gaps can provide a foundation for further investigation into students' conceptions of this complex SSI. Our second research question is: how do students support their position on the biofuels issue before and after a class focused on SSIs?

Our third goal is to document how an SSI-focused course using formal decision-making models influenced the quality of students' personal reasoning about their position on biofuels. We use the phrase "personal reasoning" to indicate an individual's view of how a controversy should be resolved or what a person evaluates as acceptable actions for society to resolve a problem (Grace, 2009). We elicited individual students' personal reasoning about biofuels before and after the class. We hypothesized that the classroom activities about the science of biofuels and use of the seven-step decision-making framework to support formal decision-making would enhance quality of students' personal reasoning about biofuels policy support after the course. Specifically, we expected to see a decrease in students' sentimental appeals, and an indication of greater students understanding of the biofuels issue based on an increase in students' range of reasoning themes. Therefore, our third research question is: did the quality of students' personal reasoning about biofuels increase after a class focused on SSIs?

Method

Classroom Context

At a large mid-western university, an introductory course, *Science and Decision-making for a Complex World* is required for all students in the agriculture and natural resources college. The students included those from a range of STEM (two-thirds of the students) and non-STEM (one-third) majors. Most of the students (eighty percent) were 1st-year students. The course was organized around five lecture courses per year with approximately 120 students each, that met for two seventy-five minute blocks each week for ten weeks and four associated recitation sections that met each week for fifty minutes for fifteen weeks. Each lecture was characterized by active learning strategies, peer instruction, and group discussion. Graduate students were associated with each recitation section and also attended lecture, allowing us to adopt a learning assistant model (Otero, Pollock, McCray, & Finkelstein, 2006; Talbot, Hartley, Marzetta, & Wee, 2015) where graduate student learning assistants engaged students during discussion in lecture, evaluated the students and led discussion in recitation.

The course was designed around two-week modules focusing on four salient SSIs to students living in the region: (1) Should you eat organic or conventional food? (2) Should you use biofuels in your car? (3) Should we hunt mountain lions? and (4) Should we further restrict the amount of water used for agriculture? For each of these SSIs, we asked students to investigate the economic, environmental, ethical, social, and cultural aspects relevant to the problem and to develop opinions about each SSI based on their values and scientific information. During each unit, the students had two main points of assessment. The first assessment asked students to evaluate claims and evidence related to each issue in both popular media articles and primary research journal articles. Then the students were asked what information they still need about the issue in order to form an opinion or make a decision. The student then sought this information and evaluated whether or not they have been successful in finding trustworthy information that answers their question. The second assessment asked students to follow a seven-step decision-making process to explain what they think could be done to solve the problem:

(1) Define the Problem: What is the crux of the problem as you see it?
(2) Options: What are the options? (List the possible solutions to the problem.)
(3) Criteria: How are you going to choose between these options? (Explain important considerations and what is valued in an outcome.)
(4) Information: Do you have enough information about each option to evaluate based on your criteria? What scientific evidence is involved in this problem? What additional information do you need to help you make the decision?
(5) Analysis: Discuss each option weighed against the criteria. What are the tradeoffs of each option?
(6) Choice: Which option do you choose?
(7) Review: What do you think of the decision you have made? How could you improve the way you made the decision?

These seven steps are based on a framework developed by Ratcliffe (1997) to addresses areas of students' difficulty in decision-making and is akin to structured decision-making processes from the decision-sciences (Gregory et al., 2012; Hammond et al., 2015). We have found it to be a useful tool to support students' decision-making about SSIs because of its clarity, simplicity, and wide applicability to issues. This tool for decision-making has been used in subsequent studies at a high school level with conservation biology topics (Grace, 2009; Grace & Ratcliffe, 2002; Lee & Grace, 2010).

For the two weeks of the biofuels unit, activities that the students engaged in during the first lecture included a discussion about our current options for energy supplies for transportation, a comparison of the origin of fossil fuels and biofuels, and the results of increased greenhouse gases in our atmosphere. During the second lecture the students did a life cycle analysis comparison of fossil fuels and biofuels made of corn and of cellulosic materials. During the third lecture a guest speaker and expert on biofuels discussed biofuel efficiency, policy and technology. During the students' recitation they read a media article on using native grasses for a biofuel, discussed the "purpose" of biofuels including reducing dependence on foreign sources of energy and finding renewable sources of energy that do not increase greenhouse gases, then compared multiple potential feedstocks for biofuels. The final lecture included a discussion on potential consequences of a food (or feed) crop being used for a fuel, a quiz on the science content of the unit, and time to work in groups on the seven decision-making steps.

Data Collection

We used both qualitative and quantitative data in a mixed methods approach to investigate our research questions. Before and after instruction, students were given an assignment to complete an online survey via a Qualtrics link that asked "what we should do" and "why should we do it/not do it?" about specific SSIs, in addition to other questions that are not reported on here. In order to shorten the survey, a random subset of the students (*n*=53, among two lecture sections taught by the same instructor) received the question about biofuels both pre and post-test. This subset of students were representative of the class as a whole and were 40% male, 60% female, 67% STEM majors (Forensic Science, Animal Science, Mechanized Systems Management, and Fisheries & Wildlife were top majors), and 33% non-STEM majors (Agribusiness, Agricultural Education, and Hospitality, Restaurant & Tourism Management were top majors), 57% were from rural areas, 29% were from suburban areas, and 7% were from urban areas. The majority were in-state students or from a nearby mid-western state, and there were four international students.

The text for the biofuels pre/post question was:

> Our culture is energy hungry! A relatively new way to solve our energy needs is to use biofuels. Biofuels are fuels made from living or recently living organisms. There are many sources of biofuels that create ethanol or diesel. A commonly used biofuel is corn ethanol. Currently, approximately 40% of the corn grown in the U.S. is used to create ethanol fuel. Corn ethanol is a boost to rural farmers, is a domestic source of energy and some evidence suggests it may reduce carbon dioxide emissions into the atmosphere. Some people point to problems with corn ethanol including "food vs. fuel," sustainability, deforestation, and water resources.
> 1) What do you think should be done about this problem? Should we burn corn ethanol for energy?
> 2) Why should we do it/not do it?

All of the students who gave permission to analyze their responses and completed a pre and post survey were compiled and de-identified before analysis.

The pre-survey, given before instruction, included likert-scale questions to assess students' environmental value orientations based on the Value-Belief-Norm (VBN) Theory (Stern, 2000). The scale (De Groot & Steg, 2008) consists of 12 items that measure an individual's orientation along three sets of beliefs regarding human–nature relationships (i.e., altruistic, biospheric, egoistic) according to students' response on a 8-point scale (-1 = "opposed to my values," 1= "not important" to 7="extremely important") to statements such as "control over others, dominance" (egoistic) "equal opportunity for all" (altruistic) and "protecting natural resources" (biospheric). Because values are stable over time we did not measure value orientations in the post-survey. Students' likert scale selections to the 12 statements were averaged across all statements within each of the 3 value orientations.

Data Analysis

Student responses to the biofuels question “What do you think should be done about this problem? Should we burn corn ethanol for energy?” with a claim about “what should be done” that revealed their overall stance on corn ethanol as a biofuel and their personal reasoning to support their stance. The students overall stance towards biofuels were coded as “pro,” “moderate” and “con” according to the level of support students gave towards corn ethanol as a biofuel. These responses were coded for their overall stance by two independent coders, one of which was the first author and the other a research assistant. Inter-rater reliability was assessed using Cohen's Kappa computed for each variable (Cohen, 1960, 1968). We considered $\kappa \geq 0.6$ as generally acceptable and representing a substantial level of agreement above chance (Lombard, Snyder-Duch, & Bracken, 2002) with an overall 96% agreement between coders.

Each student supported their stance about what we should do about the biofuels problem in response to “Why should we do it/not do it?” We found individual students gave between 1-4 different personal reasoning statements in response. We categorized statements from each student based on themes that emerged using the constant comparison method (Creswell & Clark, 2011) and coding in several iterations until consensus on the themes was reached. We grouped each of these themes into three categories of reasoning characteristics (following Grace, 2009 and, Kuhn, Shaw & Felton, 1997) that represented levels of argumentation quality. Kuhn et al. (1997) devised a pre- and post-survey hierarchical scheme for classifying quality of reasoning about capital punishment. Key factors relating to quality of argument were: i) consideration of the function of capital punishment and ii) justification for or against the practice. We adapted this scheme for arguments around biofuels. The resulting hierarchical groupings we used were:

1. ‘Non-justificatory arguments,’ which are not justified and consequently have little or no argumentative force. Most reasoning in this category was based on an appeal to sentiment.
2. ‘Nonfunctional arguments,’ focus on the conditions that make biofuels justified, but do not consider the function of biofuels.
3. ‘Functional arguments,’ where justification for the judgment includes a consideration of the function or purpose of biofuels. Within this category includes reasoning that relates biofuels to the alternatives.

We asked three biofuels experts a series of questions to validate our thinking about the purpose of biofuels for use of this coding scheme. In their response to “What are the main purposes of using biofuels as an energy source?” all three emphasized reducing greenhouse gases and having a renewable source of energy, and one expert included increasing air quality and U.S. security by using an alternative to oil. Therefore, we included functional arguments as those that argue in their personal reasoning statements about either a) carbon dioxide in the atmosphere, b) a renewable source of energy or c) a domestic source of energy, and these statements were scored as a Level 3.

Other arguments in personal reasoning statements about economic advantages to the local region, whether or not a food crop should be used as a fuel or an argument that biofuels are vaguely better or vaguely worse for the environment were considered non-functional arguments that may add justification for or against biofuels, but do not address the primary function of biofuels, and these statements were scored as a Level 2. Students who gave non-justificatory arguments gave personal reasoning statements such as “biofuels are a good idea” or “biofuels are a bad idea” which we regarded as an appeal to sentiment, and scored as a Level 1. Student responses were coded for themes by the same two independent coders, and a $\kappa \geq 0.6$ inter-rater reliability standard was achieved with an overall 70% agreement among coders. We coded students’ statements based on these themes regardless of their overall pro, moderate, or con position; for example, level 3 statements included those who argued that biofuels reduce carbon dioxide emissions and those who argued that biofuels do NOT reduce carbon emissions. As mentioned earlier in this article, many of these arguments in support or against biofuels are subject to debate within the scientific community.

All statistics were conducted in Stata/SE (v. 13.1, StataCorp, College Station, TX). Pre- and post- differences between biofuels positions and argument quality levels were measured with Pearson’s Chi-square tests. We ran a correlation to explore the relationship between biospheric and egoistic value orientation scales. A paired t-test measured the difference between pre- and post-argument quality.

Results and Discussion

We begin our results and discussion with a description of students overall stance towards biofuels and an exploration of the relationship between student value orientations and their decision-making about biofuels. Secondly, we describe themes in student reasoning about biofuels and describe our analysis of changes in quality of students' personal reasoning in their supporting statements before and after the course.

Students' Overall Stance towards Biofuels

The majority of students held pro-biofuel positions before (*n*=44) and after instruction (*n*=32; Figure 1). Students with a "pro" biofuels position responded in support of the technology, for example "We should burn more corn ethanol and other biofuels and burn less fossil fuels." "Moderate" positions were second most frequent (*n*=7 pre; *n*=18 post), and students who had this stance presented a mixed sentiment that both supported corn ethanol as a biofuel and felt that its' use should be limited or modified for improvement, for example: "Yes, but not as a major source of fuel. It causes too many problems on its own to completely replace fossil fuels." Few students had a "con" biofuels stance (*n*=2 pre; *n*=3 post), primarily denouncing corn ethanol as biofuel and focusing on alternative biofuels, for example, "I think corn ethanol shouldn't be burnt for energy, instead alternative sources of energy could be used like corn stover." The difference between pre- and post-survey stances overall was significant (χ^2= 10.92; p<0.05). Thirty-eight percent (n=20) of students changed overall stances towards biofuels from pre- to post-survey (Figure 1).

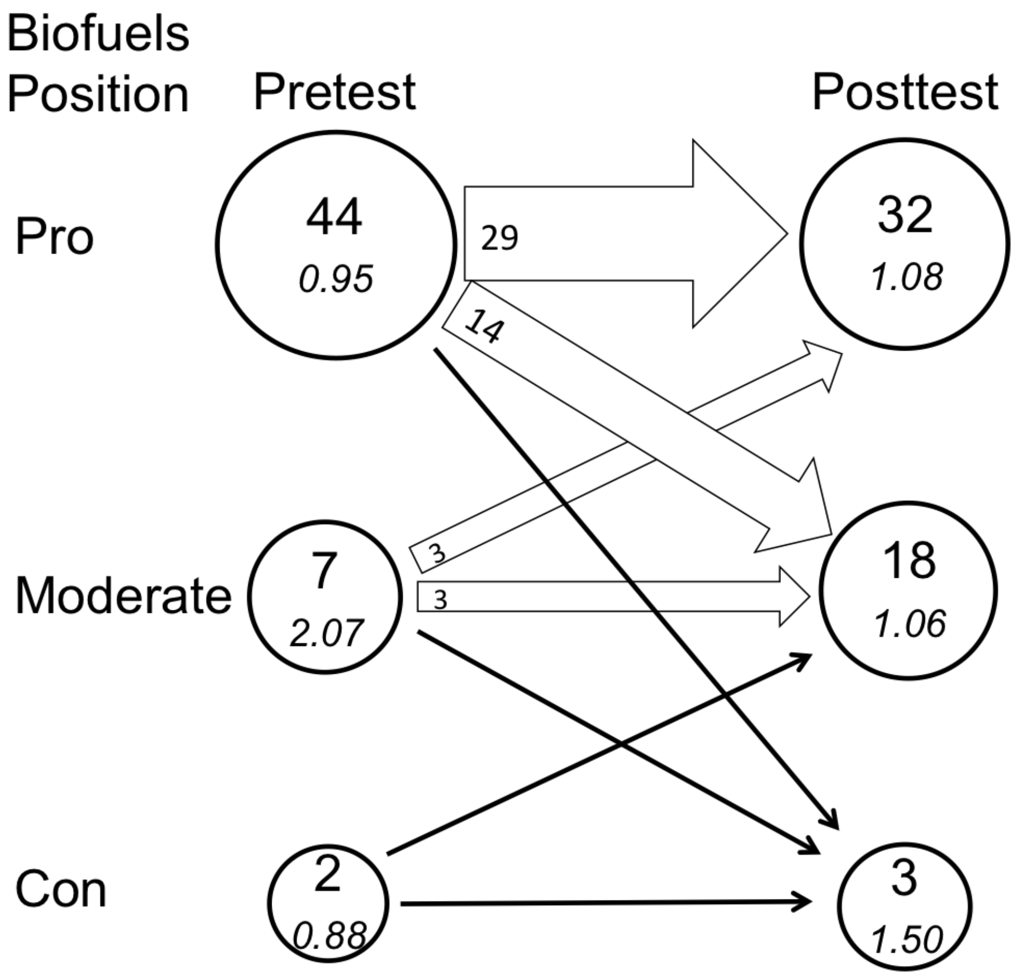

Figure 1. Change in overall position about biofuels (*n*=53). Circles include sample size and mean "Bio-Ego" value orientation scale in italics for each pre- and post- position group. Value orientations predicted students' pre-survey (p<0.001) but not post-survey position. Arrow size tracks the number of people who changed stances between pre- and post-surveys, a single line represents one person.

The largest shift occurred from pro- to moderate opinions about biofuels (n=14). Grace (2009), who used a similar decision-making framework for a wildlife conservation issue with 15-16 year olds, found that three-quarters of the students modified their opinions, and recognized a shift in opinion among so many students as a feature of good quality argumentation. A smaller proportion of students in this study changed their stance towards biofuels.

Value Orientations and Overall Stance towards Biofuels

We determined if students' value orientations measured on the pre-survey predicted students' stance (i.e., pro, moderate, or con) about biofuels either before or after the class, with the expectation that value orientations would predict stances toward biofuels to a greater extent when students engaged in informal reasoning. Overall students' value orientations were higher for altruistic (mean 5.14 ± 1.14 S.D.) and biospheric value orientations (mean 5.07 ± 1.32 S.D.) than egoistic (mean 3.97 ± 1.16 S.D.). We found students' scores for egoistic, altruistic and biospheric value orientations were not statistically predictive of students' overall stance on biofuels.

De Groot & Steg (2008) found that in most cases within their study, egoistic value orientations predicted less environmental concern while biospheric value orientations predicted more environmental concern. In order to maximize the separation between students' level of environmental concern, we created a fourth variable, "Bio-Ego," calculated as the difference between a given students' biospheric score and egoistic score on the value orientation survey. In our dataset, there was no relationship between egoistic and biospheric scores on the value orientation survey (correlation analysis: $p<0.05$; $X^2=0.29$); therefore, the new variable weighed the relative importance of egoistic versus biospheric scores to give additional information about students' value orientations. This "Bio-Ego" variable ranged from 4.75 (high biospheric, low egoistic) to -4.25 (high egoistic, low biospheric) with a median value of 1.25.

The "Bio-Ego" value orientation score that we calculated did predict overall position of pre-survey stance (Pearson's Chi-square test: $\chi^2= 77.08$; $p<0.001$) but not post-survey stance ($\chi^2= 50.68$; $p>0.05$; Figure 1). These results suggest that students were more likely to use informal decision-making processes that rely on value-based heuristics at the beginning of the course as opposed to the end. In the pre-survey, students who had moderate stances were higher on the "Bio-Ego" scale, meaning they were more biospheric than egoistic, compared to students who had a "pro" stance towards biofuels (Figure 1). Therefore, students with a stronger biospheric value orientation and a weaker egoistic value orientation were more likely to moderate their position with statements that included limited enthusiasm for corn ethanol as a biofuel.

The largest change in stance between the pre and post survey was 14 students who moved from "pro" biofuels to "moderate." During the course students engaged in learning activities around biofuels as well as a formal decision-making process that asked students to consider multiple objectives and solutions for biofuels, which may have contributed to an increase in number of students who had more nuanced views of biofuels. So, by the end of the course, the connection between value orientations and biofuel stance was less direct because students had additional resources upon which to draw during decision-making, and some students who initially had a "pro" biofuels stance included potential negative societal consequences of using biofuels as well as considerations of alternatives to corn ethanol in their reasoning after the course (see discussion of themes below).

Themes in Students' Personal Reasoning about Biofuels

We found sixteen themes consistently emerge from students' responses to support their stance on corn ethanol as a biofuel. Students' personal reasoning statements primarily dealt with environmental and economic dimensions of the biofuels issue. We separated the themes into levels of quality based on how well the statement addressed the primary function of biofuels or provided justification for biofuels (Table 1). Overall we found evidence of a larger range of students' personal reasoning themes at the end of the course, and an increase in awareness of tradeoffs at the end of the course and an increasing ability to evaluate the advantages and disadvantages of alternative outcomes.

Overall, we found similar themes in students' personal reasoning statements about what should be done about biofuels before and after instruction. Each student gave between 1 and 5 statements to support their claim about biofuels with an average of 2.2 statements per student on the pre-survey and an average of 2.5 statements per student on the post-survey. Below we describe students' reasoning with each of the themes.

Table 1. Types of arguments in personal reasoning statements given by students (n=53) pre and post. Themes are grouped by argument quality using a reasoning framework based on Kuhn 1997.

Coding Criteria	PRE	POST
Level 3: Functional arguments where justification for the judgment includes a consideration of the function or purpose of biofuels.	**20**	**19**
Biofuels do (might, or do not) reduce CO_2 in the atmosphere	10	14
Biofuels are a renewable source of energy	6	0
Biofuels are a domestic source of energy	4	5
Level 2: Non-functional arguments focus on the conditions that make biofuels justified, but do not consider the function of biofuels.	**86**	**110**
Biofuels help the rural/state/general economy	25	19
Using a food crop for fuel is NOT a problem	10	13
We should use biofuels because there is a lot of corn produced	16	10
Biofuels are vaguely better (or worse) for the environment	11	18
We should use an alternative to corn grain (e.g. cellulosic, algae, solar, corn stover)	5	19
Biofuels may have a negative impact on natural resources (water, soil, deforestation)	5	9
Using a food crop for a fuel IS a problem	6	16
Biofuels could lead to new technology	2	4
Other non-functional argument (e.g. biofuels don't deplete “natural resources,” biofuels reuse dead organisms, ethanol is less fuel efficient)	2	6
Level 1: Non-justificatory arguments which, are not justified and consequently have little or no argumentative force. Most reasoning in this category was based on an appeal to sentiment.	**27**	**16**
Biofuels are a good idea (generally, vaguely)	10	6
Other sentiment based (e.g. it is/isn't hurting anyone, I’m fine with it, we make money on our farm)	10	7
We should educate people about agriculture	3	2
Ethanol is cheaper for me at the pump than gasoline	4	1
Total Personal Reasoning Statements	**133**	**145**

Functional Personal Reasoning

Greenhouse gases. Few students, only 10 students pre, and 14 students post, included specific reasoning about greenhouse gases or carbon emissions in the support of their claims about biofuels. The majority of these students argued that biofuels reduce greenhouse gas emissions, with the exception of a few students (2 out of the 10 students pre, and 3 out of the 14 students post) who qualified their response by saying that there is a “chance biofuels could” or “biofuels can sometimes” reduce greenhouse gas emissions, or qualified their response by saying that biofuels “reduces [greenhouse gases] a little.” Only one student in the post-survey said that biofuels still “create CO_2” to argue that biofuels do not necessarily reduce greenhouse gas emission. We expected that the number of students who specifically mentioned greenhouse gases would be larger, given the proportion of class time given to discussing the contribution of greenhouse gases to global warming and carbon emission life cycle analysis. Vague notions of global climate change, specifically the role of carbon dioxide in global warming, have been observed in other contexts (Bostrom, Morgan, Fischhoff, & Read, 1994; Dauer & Anderson, 2014; Leiserowitz, Smith, & Marlon, 2011). In support of the notion that students in this course maintained a vague understanding of climate change, a larger number of students reasoned about whether biofuels were better or worse for “the environment” both before and after the course (discussed further below, Table 1).

The number of students who argued that we should use biofuels because they are a renewable source of energy as compared to fossil fuels decreased from 6 in the pre-survey to 0 in the post-survey. The student statements in this theme were that “biofuels are renewable” or the student advocated using biofuels because of their concern about running out of fossil fuels. There were several students who vaguely stated that “biofuels are better than fossil fuels” without specifying why (not coded). Additionally, few students argued either in the pre or post surveys that we should use corn ethanol because it is a domestic source of energy.

Justified, Non-functional Personal Reasoning

Biofuels, corn production and economy. Many students had economic themes in their personal reasoning about what to do about biofuels, which may be unsurprising given that the biofuel industry is worth billions of dollars and has supported jobs and economic growth in the region. However, the number of students who included economic personal reasoning statements decreased somewhat between pre and post surveys. All economic themes were classified as Level 2, meaning that they are justifications but not the ultimate purpose for using biofuels. We saw two types of economic arguments within the students' personal reasoning statements. One category consisted of general statements about how biofuels "benefit local farmers," "boosts our economy," "brings a lot of income into the agricultural community," or even more strongly "without corn ethanol many U.S. farmers would be out of a job."

Another economic-related category centered on reasoning that we should use biofuels because of high corn production. Some students stated this in a vague way "There is no corn shortage that I'm aware of…" Or some students used the idea that a lot of corn is grown as reasoning for why we need not be concern about using a feed crop for a fuel in terms of food supply or food prices, for example, "We are currently doing just fine with growing corn for both food and fuel." But other students were clearer in their economic arguments about creating a non-traditional market for corn and thereby increasing demand and prices for corn. For example "Corn for food is selling for less and less, making it hard for any farm that is not industrial sized. Having a new market for corn will help struggling farmers and increase the amount of competition in the market, benefiting consumers as well" or "it gives farmers another market for their product." Overall, these statements decreased somewhat, from 16 to 10, pre to post survey.

Better (or worse) for the environment. Many students argued that biofuels are better for the environment by stating such things as "I believe that burning corn ethanol is positive for the environment" without further details about how biofuels are better for what aspects of the environment. We grouped students into this "non-functional" argumentation category for their vague notions of "the environment." All of these students claimed that biofuels are *beneficial* for the environment except for 3 out of the 18 post students who claimed in a vague way that biofuels are negative for the environment. Many scientists argue about the possible negative impact of biofuels on aspects of the environment including soil and water conservation, biodiversity and eutrophication (Joly et al., 2015) so more specific reasoning is necessary to build a clear functional argument for the students' position.

Using a food crop as a fuel. Students were mixed in terms of whether they felt there was substance behind the idea that using farmland or crops for biofuels has a detrimental impact on the food supply or food prices, or what is known as the "food versus fuel" debate. Many more students mentioned the food versus fuel debate in the post survey in either a positive or negative light; overall 16 students mentioned the food versus fuel debate in the pre survey, and 29 students mentioned it in the post survey. In general, post responses of the students were more articulate and indicated a greater understanding of this particular issue. Most of the students who felt that the "food versus debate" was not an important issue in the pre survey (10 students), reasoned along the lines that "in the U.S. most of the corn that is grown is used as animal feed" and presumably was not affecting human food systems. Many students said that "we are producing a lot of corn, so we won't have competition between food and fuel." These sentiments may be reflecting the abundant corn production and low commodity price for corn, particularly during 2015 which set a record for corn yields in mid-western states (Bergin, 2016). Post responses that using a food crop for a fuel was not a problem (13 students) included many similar sentiments, but were more varied, and included the idea that hunger in non-US countries are more influenced by food distribution issues and are not the fault of biofuels, or that biofuel production does not hurt food prices in the United States.

Those who argued that using a food crop for a fuel was a problem in the pre survey (6 students) were vague in their notion of this issue. However, in the post survey students were more articulate, most students who felt like the "food versus fuel" debate was a real problem (16 students) mentioned the importance of finding an alternative source of plant biomass for biofuels and included statements like "the government should prioritize food over fuel… [and find] a better source of fuel can be used that does not bother the food system."

Developing alternative technology. The number of students who mentioned some alternative technology beyond corn ethanol increased from 5 on the pre survey to 19 on the post survey. In the pre survey there was only one student who mentioned a specific alternative feedstock, and the remaining 4 students talked about alternative technology to biofuels in a vague way, such as "we should look for better options so we don't have to only use corn ethanol." In the post-surveys, however, students were much more specific about potential alternatives. At least 7 students mentioned algae as a potential feedstock for biofuel that would not compete with food supplies and requires less agricultural input. At least 5 of the students mentioned a specific secondary feedstock such as corn stover or switchgrass.

Impact on natural resources. More students mentioned the potential impact of biofuels on natural resources such as water and soil quality and deforestation in the post-survey (9 students) compared to the pre-survey (5 students). In particular, the majority of the 9 students who mentioned natural resources focused on water consumption during biofuel production as problematic. This may reflect a greater awareness of water issues after one of the units of the same course focused on this topic.

Non-justificatory Personal Reasoning

The overall number of students who appealed to sentiment and gave non-justificatory personal reasoning statements about what "we should do" about biofuels decreased from 27 to 16 between pre and post. Students in this category gave arguments such as "I think that burning corn ethanol is fine," "using corn ethanol energy is the cheaper and smarter idea," or "the intent behind it has been very positive." Some argument themes were categorized as non-justificatory because they had more personal than societal relevance, such as making a profit on a family farm, or the cost of fuel at the pump. Additionally, there were several students whose personal reasoning included an argument that the problem with biofuels would be solved if more people were educated. These types of statements seemed to arise from frustration that others' do not see things in the same way, and were embedded in emotion rather than reason. For example, "If corn ethanol is going to be burned for energy and there are people that oppose that, then the public should be better informed on its benefits." Or "We should educate people because many probably do not know what the process of 'burning corn' really is. They most likely do think it is a waste of food."

Change in Students' Personal Reasoning Quality

We explored whether course activities focused on formal decision-making about biofuels influenced the quality of students' personal reasoning about biofuels. We investigated changes in quality in two ways, first we examined argument quality levels at the unit of personal reasoning statements that were given across all students (an average of 2.2 statements per student on the pre-survey and 2.5 statements per student on the post-survey), and secondly we looked at the mean argument quality of each individual student as the unit of analysis.

We found that there was an increase in overall argument quality when analyzed at the unit of personal reasoning statements across all students. There were a total of 133 personal reasoning statements given by the students on the pre-survey, and 145 on the post. The proportion of the personal reasoning statements that were in each of the three levels was not significantly different between the pre and post survey (χ^2= 3.61 p>0.05 Figure 2).

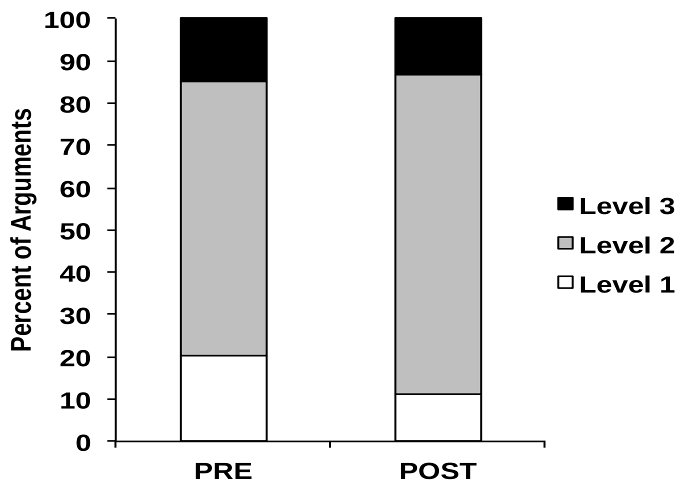

Figure 2. Percent of arguments across all students given within each level of argument quality. Across all 53 students there were 133 argument statements Pre, and 145 argument statements Post. The overall pattern of argument quality was not significantly different between Pre and Post (χ2= 3.61; p>0.05).

However, the number of statements in the lowest quality category (level 1) decreased by 41%, moderate quality arguments (level 2) increased by 28% and highest quality arguments (level 3) decreased by 5%. Across all students there was an overall decrease in the number of personal reasoning statements that had little argumentative force, and an increase in the number of personal reasoning statements that justified biofuels. The increase in level 2 arguments corresponded to students more frequently discussing several themes: 1) using an alternative technology or biofuel feedstock beyond corn ethanol, 2) the food versus fuel debate and 3) the environment or natural resources. The decrease in proportion of level 1 reasoning statements was due to less frequent level 1 themes (from 27 total to 16) in students' responses.

For each student we calculated a mean argument quality score, which averaged quality scores across all statements given by a student. The mean argument quality across all students did not significantly change from the pre- (mean = 1.9± 0.45 S.D.) to the post-surveys (mean = 2.0 ± 0.37 S.D.; t=1.22, df=52, S.D.=0.60, p>0.05). When comparing individuals between pre and post, less than half of the students (42%) had an increase in mean argument quality on the post-survey.

In our study we found that any gained ground in argument quality as a result of the course came from an increased overall frequency of certain level 2 justifications in post-surveys, and a decreased frequency of level 1 weaker appeals to sentiment, while most individual students did not necessarily increase quality of argumentation. The themes that increased the largest margin (>10 student statements) were students who felt that 1) alternatives to corn ethanol should be pursued and 2) using a food crop for fuel is problematic. Increases in these themes indicate an increased awareness of multiple potential courses of action, and an increased awareness of the consequences and tradeoffs of biofuels for society as informed by science.

Conclusion

We found that value orientations were a useful measurement to explore students' formal and informal decision-making processes around biofuels. Our results support our proposal that value orientations are more likely to predict students' stances when students are engaging in informal reasoning, and that change in overall stance towards biofuels was influenced by formal decision-making experience in the course. VBN Theory indicates a causal link between values, personal norms for society (what we should do) and ultimately behavior. This causal chain may be more easily observed when students give personal reasoning responses based on intuition that may include heuristics and biases. Student practice using formal decision-making practices was intended to reduce cognitive biases and aid recognition of multiple relevant values, consequences, and tradeoffs. We found that a portion of students in the course changed their stance on biofuels in a direction that was less predictable based on value orientation, which may be an indication that they were less likely to make a quick, heuristic-based judgment about what we should do about corn ethanol by the end of the class. This research makes a significant contribution to understanding the role that student values play in decision-making in a classroom, and how science education researchers may investigate or document improvement in students' appropriate use of values and value-tradeoffs in decisions about socioscientific issues.

The findings of this report may be useful in helping instructors understand how students understand and reason about biofuels at an introductory college level. We found that students supported their stance towards biofuels with personal reasoning statements that primarily dealt with environmental and economic dimensions of the issue. Students' personal reasoning quality did not increase in terms of increasing arguments about the functionality of biofuels for reducing greenhouse gas emissions, renewable energy or a domestic source of fuel. However, personal reasoning quality increased somewhat in terms of more justificatory arguments and less sentimental arguments. Themes that emerged to a greater extent in the post-survey revealed that students were more likely to consider potential negative environmental and social consequences to biofuels and recommend alternative solutions. This reveals greater student awareness of tradeoffs at the end of the course and an increasing ability to evaluate the advantages and disadvantages of alternative outcomes. More research needs to be conducted to determine if the use of a formal decision-making support tools versus the SSI course in general contributed to improvements in students' reasoning quality.

Structured decision-making tools such as the one used here may help students become informed citizens equipped to make evidence-based decisions regarding challenging policy issues. Instructors can help students understand when it is appropriate to engage in formal decision-making processes to avoid cognitive biases. This paper represents a significant contribution by developing a coherent set of teaching tools that support decision-making practices and help instructors define science-informed decision-making. Practicing formal decision-making processes is a key practice for science literacy, and will help students make optimal science-informed choices that consider multiple values, alternatives, tradeoffs, and consequences.

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