PROJECT REPORT

# Making Decisions about Complex Socioscientific Issues: A Multidisciplinary Science Course

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## Abstract
A new interdisciplinary, introductory, undergraduate science course was designed to help students develop science literacy, defined as decision-making about challenging, science-based issues in social contexts. The course, required of all undergraduates in the College of Agricultural Sciences and Natural Resources at the University of Nebraska-Lincoln (UNL) and reaching approximately five hundred students each year, affords a structured classroom setting in which students practice making decisions about local, regional, and global issues at the intersection of science and society (e.g., economics, politics, and values ethics). The goal of this paper is to provide theoretical grounding and rationale for the course, to describe key features intended to support students' developing decision-making competencies, and to outline initial observations and reflections that inform longer-term research and development efforts associated with the course.

## Introduction
The idea of "science literacy" lies at the heart of reform efforts in science, technology, engineering, and mathematics (STEM) education reform and serves as a primary rationale and global vision for the impact of systemic K-16 science education on civics and society. The National Research Council (1996, 21) has defined science literacy as "the knowledge and understanding of scientific concepts and processes required for personal decision making, participation in civic and cultural affairs, and economic productivity." Science education researchers have historically viewed science literacy as the set of STEM knowledge, orientations, and competencies that enable individuals to engage effectively with a multitude of challenging, science-based issues at the intersection of science and society, often referred to as socioscientific issues (SSIs) (Feinstein 2011; Kolsto 2001a; Sadler 2004; Sadler and Zeidler 2009). However, there remains a multitude of perspectives on *how* science literacy should be cultivated in both formal and informal learning environments. Many emphasize the need for individuals to simply know more

science. However, as Mullen and Roth state, "You can know all you need to know about your world and still not know what to do, which choices to make" (2002, 1). A key distinction must therefore be made between supporting students simply to learn science and supporting students to *learn to use science* (Bybee et al. 2009). To truly cultivate science literacy at a societal level, we must transcend the teaching of pre-determined bodies of disciplinary STEM knowledge. Instead, individuals must be actively supported to learn to leverage and employ this scientific knowledge; negotiate its intersection with social, cultural, and economic values; concretely identify relevant problems; evaluate real options for action; and move towards fundamentally different methods of accomplishing their goals. Science literacy, then, must fundamentally foreground decision-making about SSIs and how individuals mobilize STEM to support this process.

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 and Ahlgren 1989) and the National Research Council (1996), as well as by science educators themselves (Aikenhead 1985; Kolsto, 2006; Millar and Osborne 1998; Zeidler et al. 2005). As tomorrow's voters, workers, policymakers, and consumers, postsecondary students—both STEM majors and non-majors—must be prepared to examine complex SSIs and make socially responsible, STEM-informed decisions about them. Institutions of higher education have a responsibility to prepare students for all facets of life, help them master "Twenty-First Century Skills," such as integrating knowledge and decision-making, and contribute to lifelong development of science literacy. Postsecondary science learning environments can afford undergraduate students a highly effective, interdisciplinary, and collaborative experience with the STEM dimensions of the lived world. These experiences, which exhibit key elements of effective undergraduate STEM teaching and learning (National Research Council 2015), are often grounded in innovative partnerships between faculty from STEM disciplines, education, and the social and behavioral sciences.

We firmly believe that enhanced decision-making capacity can be actively taught and supported. Making high-quality decisions about SSIs involves being deliberate, rational, and paying attention to uncertainties (Kahneman 2011). However, this is a difficult process, as individuals are prone to snap judgments that are quick, irrational, and subject to error. A limited body of research on undergraduate students' decision-making about SSIs illustrates challenges they experience. These challenges include struggling to evaluate the advantages and disadvantages of alternative outcomes and to reflect on their choices (Grace 2009), being prone to place more emphasis on values than on scientific information when considering alternative solutions (Grace and Ratcliffe 2002; Sadler 2004) and having difficulty integrating knowledge gained in science with real-world problems (Kolsto 2006; 2001b). However, insights from the decision sciences provide insight into how to scaffold and support students' learning specifically to engage in more sophisticated decision-making over time, for example, by making students aware of the common psychological traps that can bias decisions, as well as teaching specific skills for incorporating both technical information and personal values into decision-making (Arvai et al. 2004). As science instructors, we are uniquely positioned to help students slow down, reason through a problem, apply scientific evidence, and thoroughly examine choices (Covitt et al. 2013).

## Science Literacy 101: Science and Decision-Making for a Complex World

We have designed a unique multidisciplinary undergraduate course entitled SCIL (Science Literacy) 101: *Science and Decision-Making for a Complex World*. The course is an introductory course required for all majors in the College of Agricultural Sciences and Natural Resources (CASNR) at UNL. During any given semester, the students include those from a range of STEM majors (two-thirds of the students) and non-majors (one-third). Most of the students (eighty to ninety percent) are first-year students. The course has been recently overhauled and redesigned with the primary objective of supporting students' science-informed decision-making. Throughout the course, students practice making science-informed decisions about topics such as water, energy resources, conservation of biodiversity, and food production using creative decision-making tools whose development was informed by theory and research from STEM education and the decision sciences (Arvai et al. 2004; Feinstein et al. 2013; Kolsto 2001a; Ratcliffe 1997).

## *Course structure*

The course is organized around (a) a lecture component with approximately 120 students per lecture section who meet for two seventy-five-minute blocks each week for the first ten weeks of the semester, and (b) associated recitation sections that meet each week for fifty minutes for fifteen weeks. During the last five weeks of the semester the lecture does not meet so students can focus on their final projects in their small groups associated with each recitation. Each lecture lesson is characterized by innovative active learning teaching strategies including think-pair-share, in-depth learning activities, large and small group discussion, and clicker questions (Eddy and Hogan 2014; Freeman et al. 2014; Haak et al. 2011; Lane and Harris 2015), peer instruction in assigned permanent groups of three or four (Cortright et al. 2005; Crouch and Mazur 2001), and the use of a Learning Assistant model. We used a Learning Assistant model for conceptual learning improvement (Smith 2009) and to reduce the student-to-instructor ratio and develop a more connected classroom community. A graduate student Learning Assistant is assigned to each recitation section, leading small-group discussions and assisting the primary instructor in the lecture class meetings.

## *SSI-based decision-making assignments*

The course is designed around two-week modules focusing on four salient SSIs to students living in Nebraska: (1) Should we hunt mountain lions in Nebraska? (2) Should we further restrict the amount of water used for agriculture in Nebraska? (3) Should we use corn ethanol for a transportation fuel? and (4) Should you eat organic food? For each of these SSIs, students are asked 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 have two main points of individual assessment. The first assessment asks students to evaluate claims and evidence related to each issue in both popular media articles and primary research journal articles. Then the students are asked what information they still need about the issue in order to form an opinion or make a decision. The students then seek this information and evaluate whether or not they have been successful in finding trustworthy information that answers their question. The second assessment asks students to follow a seven-step decision-making process based on previous work (Ratcliffe 1997) to explain what they think could be done to solve the problem while integrating scientific information that they have researched. The decision-making steps are as follows:

1. Define the Problem: What is the crux of the problem as you see it?
2. Options: What are the options? (Discuss and list the possible solutions to the problem.)
3. Criteria: How are you going to choose between these options? (Discuss important considerations and what is valued in an outcome.)
4. Information: Do you have enough information about each option? What scientific evidence is involved in this problem? What additional information do you need to help you make the decision?
5. Advantages/Disadvantages: 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?

This framework is based on a heuristic developed by Ratcliffe (1997) to address areas of students' difficulty in decision-making. We have found it to be a useful tool to support students while decision-making about SSIs because of its clarity, simplicity, and wide applicability to issues. This heuristic for decision-making has been used in subsequent studies at a high school level with conservation biology topics (Grace 2009; Grace and Ratcliffe 2002; Lee and Grace 2010). Student responses to these two major assessments are graded via a rubric that primarily evaluates them on the basis of comprehensiveness, sound reasoning, and clear and compelling explanations or arguments.

## *Data collection*

We collected data with the purpose of giving a general description of broad patterns in students' reasoning before and after their class. Before instruction and after instruction, the students were asked to respond to "what we should do?" and "why should we do it/not do it?" about the four SSIs (for full question texts see Appendix A). In order to shorten our pre/post testing format, a subset of randomly selected students from two lecture sections taught by the same instructor received any given question. Individuals received identical questions pre and post. In a previous iteration of the course taught in Fall 2014 without the decision-making heuristic, we observed that students tended toward extreme "pro" or "con" views around each issue (Dauer and Forbes 2015). We coded the student responses before and after the Fall 2015 course to determine the number of students with "pro," "con," or "moderate" stances towards each issue, which allowed us to understand the degree to which each issue was polarizing, how many students changed their stance on an issue, and how many students had "moderate" stances that included consideration of potential alternative courses of action and positive or negative consequences of these actions.

## Preliminary Observations and Reflections

The revised course using the decision-making heuristic was taught for the first time in the Fall of 2015. We found that a significant number of the students (twenty-five to thirty-eight percent across all four issues) changed their stances between pre- and post-assessment (Dauer and Forbes 2015). Other researchers acknowledge "changing one's mind" as a sign that effective reasoning and argumentation has occurred in the classroom (Grace 2009; Osborne, 2001). The overall pattern of student stances was significantly different between the pre- and post-assessment for each issue (Chi-square test; $P<0.05$ for organic, mountain lion and biofuel issues, $P=0.054$ for water issue). The number of students with a "moderate" stance decreased for the hunting mountain lion and organic food issues. For the irrigation and corn ethanol issues, there was a small increase in students with moderate

**TABLE 1.** Example Pre- and Post-Assessment Reasoning for Unit #4 (Water and Agriculture)

| | Pre-Assessment | Post-Assessment |
|---|---|---|
| | **"Con"** | **"Moderate"** |
| **What do you think should be done about this problem? Should we further restrict irrigation for agriculture in Nebraska?** | "No, we need to keep irrigation for agriculture." | "The water should be in control by an elected group of farmers who all decide what should be done with the groundwater." |
| **Why should we do it/not do it?** | "Because we cannot allow these crops to die and not be watered. We need to make sure we produce enough food." | "This way the groundwater will be used responsibly and every [farm] will get its fair share. Also this group will be able to talk and coordinate how much they use per year to keep the water from running out." |

**TABLE 2.** Example Pre- and Post-Assessment Reasoning for Unit #2 (Biofuels)

| | Pre-Assessment | Post-Assessment |
|---|---|---|
| | **"Pro"** | **"Moderate"** |
| **What do you think should be done about this problem? Should we burn corn ethanol for energy?** | "We should burn corn ethanol for energy. 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." | "We should burn corn ethanol for fuel but reduce the amount of corn that we use for fuel and use more of it for food and use more alternate biofuels such as cellulosic, or algae." |
| **Why should we do it/not do it?** | "Corn ethanol is [a] large part of Nebraska's economy. There is an ethanol plant in my hometown of A___ and it creates a lot of jobs. It is also a new source energy that be renewed." | "We should burn corn for ethanol to continue to have a sustainable fuel source so we don't completely run out of fossil fuel for energy. We should reduce the amount that we have to use though so we can use more of the world's corn crop to actually feed the growing population." |

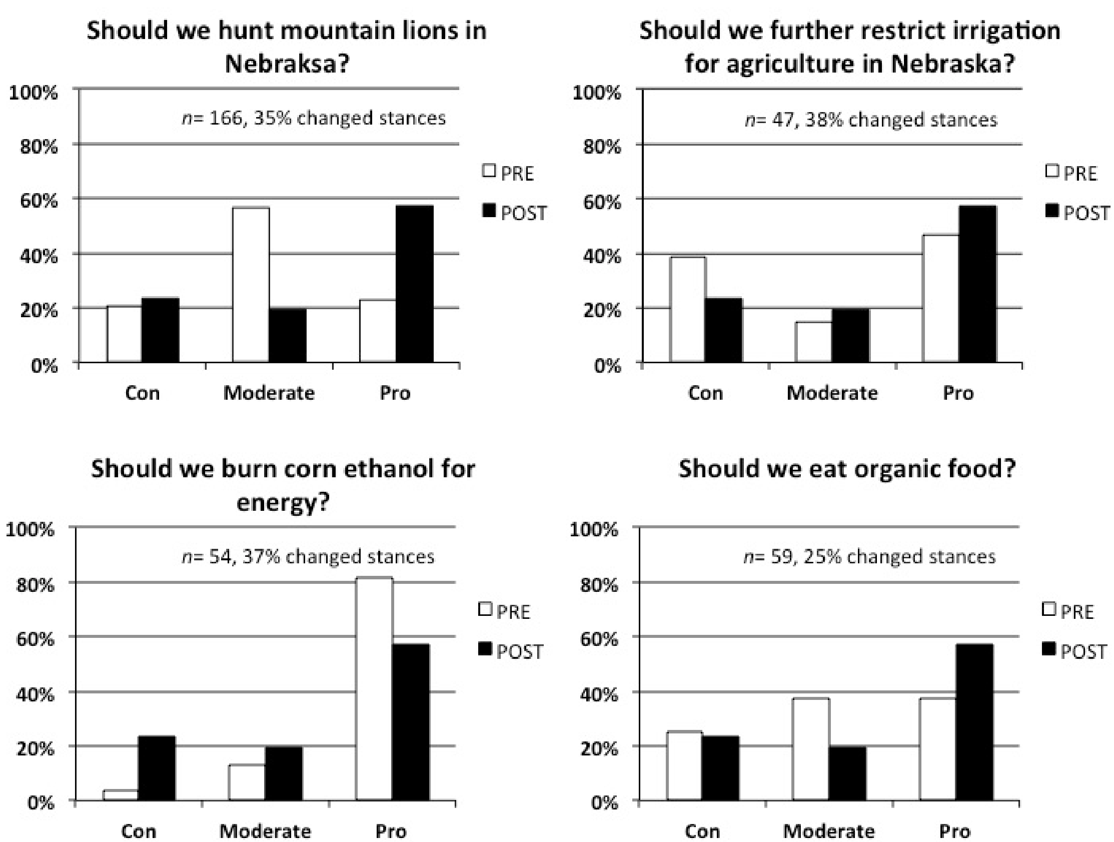
**TABLE 3.** Example Pre- and Post-Assessment Reasoning for Unit #3 (Mountain Lions)

| | Pre-Assessment | Post-Assessment |
|---|---|---|
| | **"Pro"** | **"Moderate"** |
| **What do you think should be done about this problem? Should we hunt mountain lions in Nebraska?** | "Yes" | "I don't think we should be able to hunt mountain lions in Nebraska. I think the habitats are working out rather well. The only time they should ever be hunted is if they are showing a danger for people or their animals." |
| **Why should we do it/not do it?** | "I believe people should be able to hunt mountain lions in the Pine Ridge area because of how overpopulated it's becoming. I don't think there would be any animals in that area to thin it out naturally, so I think it's important for them to be hunted to do that." | "We should not do it because there aren't exactly many of them left. They aren't hurting anything unless they are actually showing a threat to humans or their animals. There's no reason to hunt them when they aren't doing anything to anyone else and aren't overpopulating." |

stances. For these students, the moderate stance often reflected a more nuanced, informed and objective view on the issue. An example of a student who shifted from a "con" position on the pre-assessment to a more "moderate" position on the post-assessment is shown in Table 1. Other students exhibited more thorough and systemic reasoning to shift from a "pro" stance to a "moderate" stance, as shown for another student in Table 2. Some students exhibited increased learning about the parameters of the issue resulting in a shift from a "pro" stance to a "moderate" stance, as shown for another student in Table 3.

While we observed stronger, more sophisticated reasoning in some students' responses, more data analysis needs to be conducted to describe patterns in students' reasoning and to determine if the quality of students'

**FIGURE 1.** Preliminary data on Fall 2015 students' stances on each of the four issues discussed in the course pre- and post-instruction (Dauer and Forbes 2015).



arguments improved at the end of the course. Ongoing work is focused on determining if students were effective in using the seven decision-making steps in the context of the course, and if this practice influences students' informal decision-making about complex socioscientific issues.

## Conclusions

The work presented here provided a foundation upon which to build a long-term research agenda around an innovative, high-enrollment course and engage in ongoing, empirically grounded instructional design. The course provides an opportunity for future work to describe how students leverage values versus scientific knowledge and information to solve complex socioscientific problems. Our long-term research goal in this setting is to reveal challenges for undergraduate students in integrating scientific information into real-world processes. This research will inform continued development of innovative teaching tools that guide postsecondary students in obtaining more robust science literacy skills.


## Acknowledgements

Thank you to Olivia Straka for coding assistance.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## Appendix A:
## Fall 2014 Pre- and Post- Assessment Questions

Directions: Please give as much information as you can about your opinion and why you think that way. It is important to understand that there is no right or wrong answer. We are just interested in your views.

1) Modern agriculture is very different from what it was 50-70 years ago. Food production has skyrocketed due to the emergence of chemical fertilizers, pesticides and herbicides, and seed development. Our current conventional agricultural production systems are often credited for saving billions from starvation. However, some people point to problems that arise due to conventional food production, for example: eutrophication of waterways due to chemical fertilizers, pesticides that unintentionally harm bees, frogs and bats, and potential effects of these chemicals or genetically modified food on human health. One solution proposed for these problems is organic food, which the US Department of Agriculture (USDA) classifies as not allowing synthetic pesticides, chemical fertilizers or genetically modified food. Additionally, some people advocate for organic food as being healthier to eat. What do you think should be done about this problem? Should we eat organic food?

*Why should we do it/not do it?*

2) 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 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. What do you think should be done about this problem? Should we burn corn ethanol for energy?

*Why should we do it/not do it?*

3) Should we hunt mountain lions in Nebraska? Mountain lions have recently recolonized the Pine Ridge area in the northwestern corner of Nebraska. Young male mountain lions have been documented throughout Nebraska including agricultural areas where suitable habitat may be limited. Nebraska Game and Parks recently opened a mountain lion hunting season in the Pine Ridge Unit in habitat that is suitable for mountain lions and where the population is growing. Last year there was a big debate in the Nebraska legislature around hunting mountain lions including issues of animal rights, human rights, safety, biodiversity and conservation. What do you think should be done about this problem? Should we hunt mountain lions in Nebraska?

*Why should we do it/not do it?*

4) The food we eat makes up more than 2/3 of our total water footprint because of all the water needed to produce that food. Nebraska irrigates approximately 10 million acres for agricultural production. That is more than any other state in the U.S., and more than every country except Mexico. Most areas in Nebraska currently do not restrict groundwater irrigation for agriculture. The groundwater is used from the Ogallala Aquifer, which, if depleted, will take over 6,000 years to replenish naturally through rainfall. What do you think should be done about this problem? Should we further restrict irrigation for agriculture in Nebraska?

*Why should we do it/not do it?*