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RESEARCH REPORT

Socioscientific Argumentation: The effects of content knowledge and morality

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Broad support exists within the science education community for the incorporation of socioscientific issues (SSI) and argumentation in the science curriculum. This study investigates how content knowledge and morality contribute to the quality of SSI argumentation among high school students. We employed a mixed-methods approach: 56 participants completed tests of content knowledge and moral reasoning as well as interviews, related to SSI topics, which were scored based on a rubric for argumentation quality. Multiple regression analyses revealed no statistically significant relationships among content knowledge, moral reasoning, and argumentation quality. Qualitative analyses of the interview transcripts supported the quantitative results in that participants very infrequently revealed patterns of content knowledge application. However, most of the participants did perceive the SSI as moral problems. We propose a "Threshold Model of Knowledge Transfer" to account for the relationship between content knowledge and argumentation quality. Implications for science education are discussed.

Introduction

Broad support exists within the science education community for the incorporation of socioscientific issues (SSI) in the science curriculum (Driver, Newton, & Osborne, 2000; Duschl & Osborne, 2002; Kortland, 1996; Patronis, Potari, & Spiliotopoulou, 1999) and the inclusion of decision-making in the context of SSI as an integral component of scientific literacy (Bingle & Gaskell, 1994; Kolstø, 2001; Zeidler & Keefer, 2003; Sadler, 2004b). The term "socioscientific issues" has come to represent controversial social issues with conceptual, procedural, or technological ties to science. The actual issues often stem from biotechnology and environmental problems; examples include genetic engineering, cloning, local pollution issues, and global climate change. SSI are typically contentious and ill-structured, which implies that they are open-ended problems subject to multiple perspectives and solutions

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(King & Kitchener, 2004). Opportunities for argumentation (i.e., the discursive practices associated with evaluating evidence, assessing alternatives, establishing the validity of claims, and addressing counter-positions) are particularly important for science learning experiences involving ill-structured problems such as SSI (Driver et al., 2000). This study explores the argumentation of high school students as they consider and attempt to resolve socioscientific issues. More specifically, we investigate how science content knowledge and moral reasoning contribute to argumentation in the context of genetic engineering issues.

Theoretical Framework

Content Knowledge

In framing the exploration of content knowledge and argumentation, we review studies that have focused on informal reasoning in addition to argumentation. While these constructs are certainly not synonymous, they are related in that argumentation represents the social negotiation of claims and evidence, while informal reasoning represents cognitive processes involved in how people think about ill-structured problems (Kuhn, 1991; Perkins, Farady, & Bushey, 1991). Because socioscientific argumentation involves the negotiation of ill-structured problems, we include discussions from work framed in terms of informal reasoning as well as those findings more directly related to argumentation.

Discussions of SSI in the science education literature are frequently accompanied by the assumption that an individual's content knowledge contributes significantly to his/her reasoning and argumentation in the context of SSI (Dawson & Schibeci, 2003; Leighton & Bisanz, 2003; Martinez-Gracia, Gil-Quilez, & Osada, 2003; Patronis et al., 1999; Yang & Anderson, 2003). In other words, mastery of the science content knowledge relevant to a SSI is necessary for high-quality argumentation regarding that issue. This claim certainly makes sense conceptually: we would expect people who know more about the topics underlying a socioscientific issue to exhibit higher quality argumentation than their less-informed peers. The claim is also encouraging for science educators: we, as science teachers, would like to believe that the material we teach can be put to good use by our students. In fact, for many of us, this is a primary aim of education. We teach because we think the material is important for our students' lives. For instance, we teach Mendelian genetics not so that students can correctly fill out Punnett squares on a weekly examination, but so that our students develop a robust understanding of heredity that has become a fundamental aspect of modern healthcare. (Teachers may certainly have several other rationales for teaching Mendelian genetics, but they probably involve a level of application beyond the classroom.) Science education, like education in all areas, is ultimately about transfer. Unfortunately, while the goal of transfer may be ubiquitous, the desired outcome is far less common.

> The aim of all education … is to apply what we learn in different contexts, and to recognize and extend that learning to completely new situations. Collectively this is called

> *transfer of learning*. Indeed it is the very meaning of learning itself. Although some disagree, most researchers and educational practitioners, whether "liberal" or "conservative" agree … that meaningful transfer of learning is among the most—if not the most—fundamental issue in all of education. They also agree that transfer of learning seldom occurs. (Haskell, 2001, pp. 3–4; original emphasis)

The question of content knowledge and SSI argumentation is ultimately a matter of transfer. Do individuals transfer content knowledge relevant to a SSI when they are engaged in argumentation regarding that issue? The intuitive and commonly assumed answer to this question is yes; however, the literature from the broader domains of informal reasoning and argumentation suggest otherwise. In a study of content knowledge and argumentation, Means and Voss (1996) report that content knowledge is associated with some unique patterns of argumentation, but that these patterns were not indicative of higher quality argumentation. Likewise, Perkins et al. (1991) discuss a series of studies in which students from various grade levels reasoned about real-life issues with conceptual ties to various content domains. They conclude that there is no significant relationship between the quality of reasoning and content knowledge. In a review of studies of reasoning and argumentation, Kuhn (1991) suggests that "the data show that a large sophisticated knowledge base in a content domain does not determine the quality of thinking skills used in the domain" (p. 39).

While the evidence produced in general studies of argumentation and informal reasoning does not substantiate the transfer of content knowledge to argumentation practice, some science education research does support positive transfer of science content knowledge. Wynne, Stewart, and Passmore (2001) report on a study with high school students and document their use of concepts related to meiosis while working through and solving a series of complex genetics problems. In the assessment task, students are presented with anomalous data and challenged to explain novel (to the students) inheritance patterns (e.g., codominance, multiple alleles, and linkages). The authors provide evidence of the student groups using "their collective knowledge of meiosis, often in very sophisticated ways" (Wynne et al., 2001, p. 513) to generate and assess potential explanations for inheritance patterns beyond the complexity of the general model presented to the students. Keselman, Kaufman, and Patel (2004) report on student applications of biological content knowledge in the evaluation of erroneous statements regarding HIV. Students with more advanced understanding of biology, particularly the cellular basis of life, are significantly more likely to reject myths associated with the spread and treatment of HIV than their peers who demonstrated more naïve conceptualizations of basic biological principles.

These studies intimate a possible connection between content knowledge and informal reasoning but do not explicitly investigate argumentation quality and involve contexts significantly different than those provided by SSI. The subjects in Wynne et al. (2001) and Keselman et al. (2004) respond to problems that possess single correct answers, whereas socioscientific issues are open-ended and may possess several plausible solutions. Although there have been very few studies that specifically examine the issue of content knowledge transfer for SSI, several studies, whose primary foci relate to other areas, tangentially address the topic (Fleming, 1986a, b; Hogan, 2002; Tytler, Duggan, & Gott, 2001; Zeidler & Schafer, 1984; Zohar & Nemet, 2002). This work is reviewed in-depth elsewhere (Sadler, 2004a; Sadler & Zeidler, 2005a); the findings support the claim that content knowledge underlying SSI is important for argumentation regarding those issues. Zohar and Nemet offer a notable exception. They present findings from an intervention study during which enhancement of both genetics content knowledge and argumentation skills is the goal. Participants receiving explicit instruction in both content knowledge and argumentation skills show significant gains in both areas. However, the control group, which only receives instruction in genetics content and makes significant gains in a content knowledge post-test, do not show improvement in terms of their argumentation skills. In other words, increases in content knowledge alone do not mediate higher quality argumentation.

Sadler and Zeidler (2005a) present the only study (to our knowledge) that directly investigates the presumed relationship between content knowledge and argumentation in the context of SSI. They administered a test of genetics knowledge to college students with various academic backgrounds, and selected a subsample for interviews based on the genetics test results. Fifteen individuals who performed very well on the test, and 15 individuals who performed very poorly, participated in interviews designed to assess argumentation in the context of genetic engineering issues. An a priori rubric based on argumentation standards (Toulmin, 1958; Kuhn, 1991) was used to quantitatively assess the quality of argumentation demonstrated by the participants. The two groups, representing divergent levels of content knowledge, differed significantly in terms of the argumentation flaws exhibited. This statistical finding was supported by qualitative evidence that emerged throughout the interviews. Whereas the high-understanding group often revealed their content knowledge as they discussed the genetic engineering issues, the low-understanding group never showed evidence of applying content knowledge and frequently admitted their own lack of knowledge.

Sadler and Zeidler (2005a) present strong support for the presumed relationship between content knowledge and socioscientific argumentation, but they also highlight important limitations of the study. The interview subsamples were based on a maximum variation strategy ensuring a degree of variability between the groups that is unlikely to exist in most actual classrooms. Furthermore, upper-level college students, one-half of whom were biology majors, made up the sample. Given the lack of consensus among findings in this area, and Sadler and Zeidler's study limitations, the extent to which content knowledge contributes to the argumentation of high school students in the context of SSI remains an open question.

Morality

In the previous section, we stressed the fact that SSI are, by definition, ill-structured and open to several plausible solutions. At least one reason for the controversial nature of SSI is that they are typically value-laden. SSI clearly possess conceptual ties to science content, but they are also subject to individuals' moral considerations.

In using the phrase moral considerations, we are referring to factors related to an individual's determination of what is right, good, and virtuous. We construe moral considerations broadly to include formal systems of thought within moral philosophy such as deontology and utilitarianism (DeMarco, 1996), as well as value systems reflective of participation in religious traditions. This range is admittedly large, but we frame the construct in this manner so as to be inclusive of the various moral realities that individuals bring to bear in socioscientific and other real-world contexts (Sadler & Zeidler, 2004). Whereas our use of the phrase "moral considerations" is broad, we will restrict our usage of the phrase "moral reasoning" to the application of logical moral principles as conceptualized by the neo-Kohlbergian paradigm for morality (Rest, Narvaez, Bebeau, & Thoma, 1999).

Several reports have provided empirical evidence of the prominence of moral considerations in the negotiation and resolution of SSI. These studies have documented the role of moral considerations in the decision-making of subjects varying greatly in age, including middle school (Hogan, 2002; Pedretti & Hodson, 1995), high school (Fleming, 1986a; Zeidler, Walker, Ackett, & Simmons, 2002), college (Sadler, 2004c; Sadler & Zeidler, 2004), and adults (Bell & Lederman, 2003). These same studies suggest that moral considerations influence how individuals negotiate a variety of SSI including genetic engineering, biomedical research, environmental problems, and animal rights.

Research Questions

Given the theoretical backdrop just presented, we designed and conducted a study with the purpose of investigating how content knowledge and moral reasoning contribute to the quality of argumentation demonstrated in the context of SSI for high school students. In terms of the SSI, we focused on genetic engineering issues, more specifically gene therapy and cloning. Basic genetics concepts became the corresponding content knowledge on which we focused. We employed a mixed-methods approach whereby we used quantitative instruments to measure genetics knowledge and moral reasoning, and we developed a rubric to assess the quality of argumentation demonstrated in interviews focused on genetic engineering issues. To answer the following research questions we used both statistical techniques and qualitative analyses.

1. How does genetics content knowledge relate to argumentation quality in the context of genetic engineering issues?
2. How does moral reasoning relate to argumentation quality in the context of genetic engineering issues?

Methods

Instrumentation

Genetics content knowledge. The aims of the study required reliable measures of three variables: genetics content knowledge, moral reasoning, and argumentation quality. For the assessment of genetics content knowledge, we administered the Test of Basic Genetics Knowledge (TBGC; Sadler, 2003). The TBGC comprises 20 multiple-choice items that target nine different basic genetics concepts, such as the gene function, the relationship between DNA and genes, and polygenic inheritance. Instrument development and validation was supported by the assistance of five content experts, including three college professors and two high school teachers of biology. Although the test was originally administered to college students, its aim was to assess understandings of genetics "commensurate with the aims of high school genetics instruction" (Sadler & Zeidler, 2005a, p. 79). The internal consistency reported for a sample of college students was .79; a Kuder–Richardson estimate of internal consistency (KR_{20}) was also calculated with the present study's sample. The reliability estimate (r_{xx} = .67) was lower for the high school sample, but, given the conservative nature of this procedure, we concluded that the TBGC was appropriately reliable for the study.

Moral reasoning. Participants also completed the Defining Issues Test (DIT; Rest, 1979), which measures moral reasoning on general social problems. The instrument is consistent with Neo-Kohlbergian perspectives on morality (Rest et al., 1999; Rest, Narvaez, & Bebeau, 2000). This framework presumes that individuals progress through developmental stages or "schemas" that guide reasoning and decision-making in moral contexts. The most advanced schemas are based on generalizable moral principles such as justice, non-maleficence, and beneficence. "*P* scores", the most commonly used index of DIT performance, provide an estimate of the relative importance of principled moral considerations in an individual's moral decision-making. The full DIT consists of six moral dilemmas and a series of considerations that might be important for a decision-maker. Participants are asked to rank the significance of each of the considerations as they attempted to resolve the issue. The instrument has been deemed a valid measure of moral reasoning (Rest, 1979; Rest et al., 1999) and reliability estimates are fairly high. Davidson and Robbins (1978) report test–retest reliabilities in the high .70s or .80s and Cronbach's alpha index in the upper .70s. Given logistical limitations of test administration, we reduced the number of dilemmas considered by the participants from six to four. Reliability studies report that halving the instrument to three dilemmas may reduce the test–retest reliability by as much as .10, but this still produces estimates in the high .60s or .70s (Rest, 1986). Given the constraints we faced, we deemed this a necessary compromise. It should also be noted that we modified one scenario to reflect more contemporary themes. The "Newspaper" dilemma, which was originally written in the early 1970s and focused on the Vietnam War and the "rebellious" behavior of males wearing long hair, was changed to highlight conflicts in the Middle East and school policies forbidding students to wear hats in classes.

Argumentation quality. For the assessment of argumentation quality, we engaged participants in interviews during which they had to consider and attempt to resolve three controversial genetic engineering scenarios. We used a protocol similar to Sadler and Zeidler (2005a) but made modifications to account for the needs of a high school sample as opposed to college, and to enhance the technique's precision. The first author conducted all of the interviews in a private office with individual students. The interviews were audio-taped and transcribed for analysis. After a brief introduction and description of the project, the interviewer provided a basic overview of gene therapy, offered students an opportunity to ask questions, and asked students to read a short description of Huntington's disease and the use of gene therapy to eliminate the disease. The interviewer then asked participants to articulate their positions regarding the use of gene therapy in this particular context. Several probing questions were asked in order to give the participants ample opportunity to express their positions and demonstrate argumentation skills. If participants had not articulated a counter-position (i.e., they had not demonstrated awareness of multiple perspectives potentially contradictory towards their own position), the interviewer asked "Can you think of an argument that could be made against the position that you have just described? How could someone support that argument?" The students were then asked to rebut the counter-position in support of their originally articulated positions. In the cases that students were unable to describe a viable counter-position, the interviewer offered a suggestion so that each participant had the opportunity to give rebuttals. This basic interview protocol was used with two additional issues: gene therapy to enhance intelligence and reproductive cloning. Participants read brief statements describing each scenario, and the interviewer posed a series of questions designed to elicit the participants' positions, multiple perspectives, and rebuttals.

We developed a rubric to assess the quality of argumentation demonstrated in the interviews. The participants' responses to each scenario were assessed on the basis of three criteria, and the score for each criterion ranged from 0 to 2. Therefore, the maximum score for a single scenario was 6, and the maximum score for a complete interview (consisting of responses to three scenarios) was 18. The three assessment criteria were position and rationale; multiple perspective-taking; and rebuttal. For the first criterion, position and rationale, we looked for participants to offer a coherent, logically consistent argument that included an explanation and rationale for the position taken. Consistent with Toulmin (1958) and more recent efforts to assess argumentation (Erduran, Simon, & Osborne, 2004), we were interested in the extent to which participants could support their positions with grounds (i.e., data, warrants, or backings). The second criterion, multiple perspective-taking, assessed whether the participants could think beyond their stated positions to consider perspectives counter to their own ideas. The final criterion, rebuttal, dealt with how well participants could rebut a counter-position in support of their own position. In order to earn the maximum score on this criterion, a rebuttal had to challenge the grounds of the counter-position. An intermediate score was assigned if participants were able to address a counter-position but failed to challenge its grounds. Table 1 presents an overview of each criterion and how points were assigned.

Table 1. Rubric for assessing argumentation quality

Criterion	Score	Description
Position and rationale	2	Participant offers a coherent, logically consistent argument that includes an explanation and rationale for his/her position (Claim with grounds)
	1	Participant offers a coherent argument but offers little to no elaboration in terms of a rationale for the position (Claim without grounds)
	0	Participant offers an incoherent response that does not provide a rationale for the argument (No clear claim)
Multiple perspective-taking	2	Participant expresses multiple perspectives on his/her own without being prompted by the interviewer
	1	Participant expresses multiple perspectives when specifically asked to do so
	0	Participant is unable to express multiple perspectives even when specifically asked to do so
Rebuttal	2	Participant challenges the grounds of a counter-position (CP)
	1	Participant addresses a CP but does not challenge its grounds
	0	Participant is unable to point out weaknesses or address the CP directly. This may be evidenced by the participant rearticulating his/her original rationale or changing his/her original position to agree with the CP

For the purposes of this study, we operationalized high-quality argumentation in terms of participant abilities to express specific argument structures. Whereas the assessment scheme was based on participants' abilities to logically support claims with grounds, consider issues from multiple perspectives, and rebut counter-positions, the scheme did not make normative distinctions regarding the content of participants' argumentation. Even if it were methodologically possible to reliably evaluate the content of arguments beyond a nominal scale, we feel that it would be inappropriate to do so in the context of SSI because of the various frameworks that contribute to argumentation associated with these complex social issues (Sadler & Zeidler, 2005b). However, the extent to which participants apply science content and/or misconceptions is an important aspect of this project, and we address this issue in the qualitative analyses.

The analytic framework was developed prior to the research in order to establish the interview format, but at the completion of the interviews the authors worked together to "calibrate" their scoring practices so as to ensure reliable results. To begin, both authors scored 10 transcripts independently and met to discuss different interpretations. We worked to standardize our assessments of the three criteria chosen to represent argumentation quality. Although the basic criteria and scoring scheme remained the same, each of our interpretations of the interviews and the criteria point values were modified slightly in order to establish a standard approach to assigning scores. Following this initial collaboration, both authors scored each of the interviews. Inter-rater consistency was .91, and all disagreements were discussed in order to attain a consensus score.

Sample

Students from a large, urban high school in the Southeastern United States participated in the study. We targeted individuals who had completed at least 1 year of high school biology to improve the likelihood that they had at least been exposed to basic genetics concepts. Students were recruited from chemistry, physics, anatomy, and marine science classes. The participants ranged in age from 15 to 18 and were classified as sophomores, juniors, or seniors. Two hundred and twenty-one students completed the TBGC; 2 weeks later, 179 of these individuals took the DIT. The DIT has a series of internal validity measures (see Rest, 1986) that indicate when an individual's score may be an invalid measure of his/her moral reasoning. Based on these criteria, 54 students were excluded from the remaining aspects of the study. Of the remaining 125 students who completed both the TGBC and the DIT, 56 participated in interviews. Individuals were randomly selected and asked to participate in the interviews. Approximately 10% of the students asked declined. Of the 56 interviews completed, 48 were actually scored: five interviews were not transcribed due to technical difficulties, and three transcripts were deemed un-scorable. Participants providing un-scorable interviews offered responses that could not be adequately accounted for by the scoring rubric. We decided that it would be more appropriate to eliminate these data than misrepresent them by imposing an incompatible *a priori* framework.

Demographic data for the 48 individuals who completed the TBGC and the DIT and whose interviews were scored for argumentation quality are presented in Table 2.

Analyses

Statistical analyses. To explore potential relationships among genetics content knowledge, moral reasoning, and argumentation quality, we performed a multiple regression analysis. Scores on the TBGC, which measured genetics understanding,

Table 2. Demographic information

N	48
Mean age (years)	16.7
Sex	
Female	31
Male	17
Race/ethnicity	
Asian	2
Black	11
Hispanic	2
White	33

and the DIT, which measured moral reasoning, served as predictor variables. Argumentation quality as measured by the framework presented earlier served as the criterion variable. The alpha level for the analysis was set at 0.05.

Qualitative analyses. To support the quantitative findings, we also conducted qualitative analyses of the interview transcripts. This work was consistent with inductive data analysis as described by Lincoln and Guba (1985) and the constant comparative method (Glaser & Strauss, 1967). While we did not impose *a priori* taxonomies or frameworks during this phase of the study, we were particularly interested in emergent patterns that might inform the research questions. Because we had already scored the interviews for argumentation quality, we examined all of the transcripts and had begun to note recurrent trends. To further the qualitative analyses of the data, both authors independently evaluated 10 transcripts with the aim of identifying important patterns. After discussing emergent patterns and trends significant to the research questions, the first author re-read all of the transcripts in order to determine the prevalence of these trends, to ground these patterns in the data with specific examples, and to look for patterns that did not emerge in the original subsample. While the presentation of frequency data to substantiate the legitimacy of qualitative categories is deemed unnecessary by some (Eisner, 1991; Lincoln & Guba, 1985), we do think it important, particularly in an interview study with as many participants as ours, to distinguish between ideas mentioned by one or two individuals and trends that emerged among several participants. For this reason, the qualitative patterns described throughout the results section were evident in a minimum of 10% of the interviews.

Results

Quantitative Findings

Raw scores on the TBGC ranged from 3 to 16, with an average score of 9.46. (Although the instrument contained 20 items, the maximum possible score was 18. For a detailed description of the scoring process, see Sadler, 2003.) Table 3 presents

Table 3. Descriptive statistics

	TBGC	DIT[a]	Argumentation interview
Minimum score (%)	3 (16.6)	8	5 (27.8)
Maximum score (%)	16 (88.9)	58	17 (94.4)
Mean (%)	9.46 (52.6)	25.0	11.5 (63.9)
Standard deviation	3.40	12.8	3.07
Skewness	–0.10	0.76	–0.30
Kurtosis	–0.84	0.067	–0.60

[a]Percentages are not presented for the DIT because the scores represent an index measure of the likelihood that the subject would apply principled reasoning to a moral problem.

descriptive statistics for the three quantitative measures. *P* scores derived from the DIT, which can be interpreted as "the relative importance a subject gives to principled moral considerations in making a decision about moral dilemmas" (Rest, 1986, p. 4.2), ranged from 8 indicating very little consideration of moral principles to 58 indicating fairly high reliance on principled moral considerations. The mean was approximately 25, which is slightly below the established average for high school students (Rest, 1986). Argumentation scores, based on the interviews and scored via the rubric presented in the Methods section, ranged from 5 to 17. Table 4 presents interview excerpts to demonstrate how various lines of argumentation were assessed based on the scoring rubric. Each exemplar is a direct quote from an interview transcript. The code numbers preceding the excerpt identify an individual participant (P) as well as the issue to which he/she is responding; "HD" indicates a response to the Huntington's disease gene therapy scenario; "IN" indicates a response to the intelligence gene therapy scenario; and "RC" indicates a response to the reproductive cloning scenario.

The regression analysis, using DIT and TBGC scores as predictor variables and the argumentation quality score as the criterion variable, produced an R^2 value of .061 (adjusted R^2 = .019). This result suggested that genetics content knowledge, as measured by the TBGC, and moral reasoning, as measured by the DIT, did not significantly contribute to the variation associated with the argumentation quality scores. Individual correlations between TBGC and argumentation quality scores and DIT and argumentation quality scores were also not statistically or practically significant.

Qualitative Findings

We examined the interview transcripts qualitatively with the intent of detecting patterns to inform the two guiding research questions. As such, several themes emerged relative to genetics content knowledge and moral considerations in the context of socioscientific argumentation. These themes are described, and representative excerpts taken directly from interview transcript are provided in the sections that immediately follow. Figure 1 presents an outline of the emergent themes in an effort to help organize the data and descriptions that follow.

I. Understandings of Genetics
  - A. Participants Using Content Knowledge
  - B. Participants Relying on Science Fictional Accounts of Genetic Engineering
  - C. Participants Revealing Genetics Misconceptions
  - D. Participants Admitting Their Own Lack of Knowledge

II. Moral Considerations

III. Personal Choice

Figure 1. Overview of the emergent themes

Table 4. Argumentation quality scoring samples

Criterion	Score	Description	Exemplar
Position and rationale	2	Participant offers a coherent, logically consistent argument that includes an explanation and rationale for his/her position (Claim with grounds)	P11 (IN): I probably would not agree with it just because I would want the choice … if it was me I wouldn't have wanted that because I would've wanted the choice of this … I would not want someone making up their mind for me for giving me the intelligence gene. It's kinda like they are underestimating what is going to happen and what I am capable of. So, I wouldn't want someone making that decision for me.
	1	Participant offers a coherent argument but offers little to no elaboration in terms of a rationale for the position (Claim without grounds)	P209 (HD): I think it [gene therapy] is pretty cool. If you can stop someone from suffering, I think that that would be a great idea … Personally, I think that is awesome. I think it would be great to stop someone from suffering.
	0	Participant offers an incoherent response which does not provide a rationale for the argument (No clear claim)	P138 (RC): That [reproductive cloning] would make sense. There is still something that I cannot explain that is missing from it. That is why I just do not think that is necessary to clone. It is hard to really say why. It is just like I do not know; it's hard to explain.
			Interviewer: Should we use gene therapy to eliminate Huntington's disease?
Multiple perspective-taking	2	Participant expresses multiple perspectives on his/her own without being prompted by the interviewer	P10 (HD): I think so. Definitely you should use it, but some people might say it's God's plan [for people to have the disease], but if god didn't want us to use it [gene therapy] he wouldn't have allowed you to discover it and all that kind of thing, so I think it would be good. That way you have less sick people. Interviewer: Should people use cloning as a reproductive option?
	1	Participant expresses multiple perspectives when specifically asked to do so	P66 (RC): I think this is a good idea because there are people who can't have babies and they deserve a chance to have children and I don't think there's anything wrong having them looking like the mom or like the dad … Interviewer: Can you think of a reason why someone might be opposed to reproductive cloning?

Table 4. *(continued)*

Criterion	Score	Description	Exemplar
			Subject: probably people who are into religion a lot saying oh if they can't have a baby why are you trying to do all of these things. If God doesn't want it that way then why should you do it?
			Interviewer: Should gene therapy be used to enhance intelligence?
	0	Participant is unable to express multiple perspectives even when specifically asked to do so	P14 (IN): I don't think you should tamper with the genes. I don't think they should make you smarter than you are because there can be bad side effects. You may turn out to be worse off than you were.
			Interviewer: Can you think of a reason why someone might support this?
			P14: I don't know.
			P85's position: Gene therapy for Huntington's Disease should be used.
Rebuttal	2	Participant challenges the grounds of a counter-position (CP)	*Counter-position: Gene therapy irrevocably alters the natural state.*
			P85 (HD): Right now—everything has been altered. Everything has been changed … We have more knowledge today and due to the technology, mother nature has already been altered so why stop there? Why not do something to help because we have already altered mother nature with pollution and other things that have done damage. Why not do something to help?
			P37's position: Gene therapy for intelligence should be used.
	1	Participant addresses a CP but does not challenge its grounds	*Counter-position: Gene therapy for intelligence creates the possibility of creating another social division: genetic haves vs. genetic have nots.*
			P37 (IN): I do not think that people should be discriminated against because they did not get that [gene therapy]. I do not think that is right. They have their own choice. They can choose to get it or not get it so I do not think that anyone should discriminated for that just because they chose to do this or not do this.

Table 4. *(continued)*

Criterion	Score	Description	Exemplar
			P144's position: Gene therapy for Huntington's Disease should be used.
	0	Participant is unable to point out weaknesses or address the CP directly. This may be evidenced by the participant rearticulating his/her original rationale or changing his/her original position to agree with the CP	*Counter-position: We should not use gene therapy because that would be changing someone's genes and we as humans do not have the right to change genes. That is too much like playing God.*
			P144 (HD): It's true … sometimes when they do change genes around it becomes a bad result instead of a good result. So then I'm like, I'm for it and then I'm not for it.

I. Understandings of genetics. As we examined the interview transcripts qualitatively with the intent of detecting the use of content knowledge in participant argumentation, it became apparent that participants possessed a wide range of ideas about genetics, not all of which we felt comfortable classifying as "genetics content knowledge". For the purposes of this analysis, we reserved the phrase "genetics content knowledge" for genetics understandings consistent with scientific accounts of heredity. The concepts we expect students to acquire through formal science education experiences are representative of content knowledge. However, participants also revealed other understandings of genetics. Some held genetics understandings consistent with science fictional accounts of genetic engineering, and some revealed genetics misconceptions. Another group of participants acknowledged a lack of knowledge.

A. Participants using content knowledge. We found very few instances in which participants demonstrably relied on genetics content knowledge in their discussions of genetic engineering issues. Of the 48 participants, each of whom responded to three interview scenarios, only five individuals made an explicit reference to content knowledge, and the majority (three of five) only referenced specific content knowledge in regards to one of the three scenarios. Even when genetics concepts were raised by the participants, the discussion was typically brief and relatively restricted in focus. The following interview excerpts reveal the kinds of genetics knowledge participants demonstrated and also the extent to which content knowledge was discussed.

P20 (HD):	On one level, if people are going to look at the genome, we [all people] are 99.99% the same.
P49 (RC):	With *in vitro* [fertilization], you have traits from the mom and dad, but with cloning you have the exact same genes. The only difference is that you grow up in a different environment. The *in vitro* has been done and it works with humans; with cloning, we don't know yet.

B. Participants relying on science fictional accounts of genetic engineering. Whereas the number of participants demonstrating the use of genetics knowledge was quite low, many individuals did show evidence of considering depictions of genetic engineering as presented in science fiction. The effects of the media were far more prominent in discussions of cloning as opposed to the gene therapy scenarios. Several participants talked about how their ideas relative to cloning had been shaped by movies and the media. The following excerpts illustrate this trend.

P7 (RC):	If your mom passed away, you can get some of her DNA, and she can be born again. But it would take a long time for her to grow up, but I've seen a lot of science fiction where they sped up the process. So they have like a memory of the person and they have the same mind. That's what's weird about this [reproductive cloning]
P33 (RC):	I don't see anything wrong with this sort of thing [cloning].
Interviewer:	Why would you support cloning?

P33: Well, like in the movies, the next generation would be a race of super geniuses without disease and everything.

In the cases just presented, the participants explicitly mentioned media outlets as sources of their ideas. However, several other individuals expressed notions consistent with science fictional accounts of genetic engineering without acknowledging the source or indicating an awareness of distinctions between the actual potential of genetic engineering and Hollywood's versions. The following quotations demonstrate this pattern.

P7 (RC): For the most part, I'm against cloning unless it's for health reasons or something like that. Say I have a disease or I come up with a disease like cancer, and they have to take my kidneys or something. I could like have my clone on "stand-by"—not like another me walking around but like they have the water tanks. Then if they have to remove an organ that's vital to me, then I would have a match.

P80 (RC): I mean if they were doing weird stuff [with cloning] like creating armies to take over the world, I would be against it.

As the quote from P80 demonstrates, several participants possessed fantastic notions of clone armies. We believe that the most probable origin of these unrealistic ideas probably relates to science fiction accounts of genetic engineering such as the movie *Star Wars: Attack of the Clones*.

C. Participants revealing genetics misconceptions. While we found it difficult to detect instances in which participants demonstrably used content knowledge in their discussions of genetic engineering issues, we did note some cases in which participant reasoning was based on a misconception or a misunderstanding of basic genetics or genetic engineering.

P30 (HD): Yes, [we should use gene therapy for Huntington's disease] because no one needs to die. If you can do that, sure, you should. That is the next step to [cure] AIDS.

P99 (IN): The only reason why I would be against something like this [gene therapy for intelligence] is because it could go the wrong way. You could inject something into someone's brain and they could be overly smart, and they might use it the wrong way. But if it is going to be strictly used to help people, then you should help people.

Whereas the comment from P30 suggests a misunderstanding of the heritability of diseases, the comments of from P99 reveal misconceptions regarding the processes of gene therapy. P99 seems to believe that gene therapy for intelligence would have to involve medical modifications to the brain.

D. Participants admitting their own lack of knowledge. Several participants also admitted their own lack of understanding of genetics and genetic engineering, as the following quotes indicate.

P72 (RC): I mean I am sure if I knew more about it [cloning], I might be able to see it in a different way, but just given a small scenario with not a whole lot of background or stuff like that, I'm just kind of not sure.

P217 (RC): The thing is, I don't really know a lot about genetic engineering. I think I would like to learn a lot more about it. I think it's really interesting.

II. Moral considerations. Participants frequently cited moral considerations in their argumentation regarding the genetic engineering issues. Many individuals employed concepts of good and bad, right and wrong in moral contexts to reference the genetic technologies under discussion. The following excerpts demonstrate this trend.

P53 (RC): If someone could not have a kid, there are other options besides doing this [reproductive cloning] because—I do not know—cloning seems a little wrong. To duplicate the same person is just – it just seems morally wrong.

P209 (RC): Morally, I do not really know if I think that [reproductive cloning] is correct. I think that if cloning were to happen—if we did start doing that—I think the world population would rise if there were not standards. Then people would just be cloning stuff that just doesn't need to be cloned.

These examples offer an indication of the various ways moral considerations were applied. For P53 cloning felt intuitively wrong, and P209 invoked a "slippery slope" (Boss, 2002) rationale. From her perspective, the fact that cloning used in an acceptable context could enable the use of cloning in morally unacceptable contexts was enough to oppose the procedure.

A notable subgrouping of the comments indicating moral considerations was those statements that related the issues to a religious perspective. Well over one-half of the participants cited personal religious beliefs as significant factors contributing to their negotiation of the scenarios or the opinions of others. The following quotes demonstrate this category.

P144 (RC): I don't think it's [reproductive cloning] right because if you're not able to have a child … it's not God's will. If God wants you to have a child, you should have a child and you will have a child, but if it's not for you to have a child, I don't think you should tamper with it. I don't think it's right.

P189 (HD): I mean the research sounds good and I would report it and see it from like a scientific point of view, but my religion—my family's personal beliefs would be like no.

It should be noted that participants did not reveal tendencies to employ principled moral reasoning consistent with neo-Kohlbergian morality, the theoretical basis of the DIT.

III. Personal choice. An interesting trend, which was not directly related to either of the research questions but which did have potentially significant implications for socioscientific argumentation, emerged from the interviews. When confronted with a difficult counter-position, rather than articulating a rebuttal, many participants would resign themselves to claiming that the only plausible solution would be to leave the issue up to the personal choices of the individuals involved. In essence, they removed themselves from the argumentation process regardless of their initial inclinations. A typical example of this trend occurred when the participant articulated a position but was unable to present a plausible counter-position. When the interviewer offered a counter-position for the participant's consideration, he/she seemed conflicted about his/her own original arguments and those just presented. The solution was to conclude that there was no adequate solution and that the issue may only be resolved on individual bases as a matter of personal choice. The following excerpts serve as examples.

P52 (HD):	I do not believe that it [gene therapy] is necessary because I believe that if you have a disease it has to do with something natural…
Interviewer:	How might you respond to the argument that gene therapy would stop the suffering of many people and, therefore, would be a good thing to do?
P52:	If they want to use it, then I guess they can. Myself, I personally do not feel that it is necessary.

P53 (HD):	As long as I knew that the baby would be OK, then I would be for it [gene therapy] …
Interviewer:	How might you respond to the argument that we do not have the right to alter people's genes?
P53:	I am not sure because it seems like—sometimes it feels like it kind of should not be done—I am not really sure. I would just say [people should] do what they want with their kids. It is your kids so you should be able to do whatever you want with them.

Discussion

Content Knowledge

We did not find much qualitative evidence of participants actively using accurate science conceptions while resolving genetic engineering problems. Nevertheless, the lack of demonstrable signs of the application of content knowledge did not, in and of itself, rule out a relationship between content knowledge and argumentation quality. It remained entirely possible that strong background knowledge could enhance argumentation, and yet remain undetected in the qualitative analyses. This conclusion, however, is not supported by the quantitative analyses. The combined results of the multiple regression and qualitative analyses suggest that genetics content knowledge was not a significant factor in the determination of argumentation quality. Students who performed well on the TBGC were not more likely to demonstrate high-quality argumentation than their peers with low TBGC scores. The qualitative analyses suggest that applications of genetics knowledge were very infrequent throughout the interviews, even among individuals who presumably knew something about genetics. In fact, participants were more likely to invoke information gleaned from science fiction than biology class when considering controversial genetics issues.

At least three possible interpretations can account for these results. First, it might be the case that individuals just do not consider the science, particularly science as it is represented in schools, behind socioscientific issues. If this were the case, we would have no reason to believe that science instruction might contribute to improving argumentation in the context of controversial issues. This interpretation is consistent with Fleming's (1986b) conclusion:

> Knowledge of the physical world is rarely, if ever, used when analyzing and discussing socio-scientific issues. School science is the source of the colloquial expressions. It is not, from students' perspectives, a source of useful information for analyzing socio-scientific issues. (p. 696)

A second possible interpretation is that the problem is not a matter of content knowledge transfer, but rather it is a problem of context knowledge. In other words, if individuals do not have a basic understanding of the issue itself (in the case of this study, gene therapy and cloning), then content knowledge, no matter how extensive, will not have discernible effects on argumentation processes. Whereas most of the participants in this study had at least heard of gene therapy and cloning, few seemed well-versed on the specifics of either procedure. This interpretation is supported, at least in part, by the comments of several participants suggesting that they would be better prepared to respond to interview questions if they knew more about the genetic technology in question. Some of the students' misconceptions, which revealed misunderstandings related to the processes of gene therapy and cloning, lend further support to this interpretation. Conversely, it could be argued that context knowledge depends on a well-developed body of content knowledge. In this case, an adequate understanding of gene therapy and cloning requires a robust repertoire of genetics knowledge. Given this explanation, science education, with the aim of enhancing student reasoning and argumentation in the context of SSI, demands attention to both content knowledge and context knowledge. Students need more than just exposure to the basic concepts that underlie SSI; they also require sustained opportunities to consider the complexities of the SSI themselves.

A final possible interpretation is based on a knowledge threshold of sorts. It might be that content knowledge is significant for socioscientific argumentation but the relationship may be non-linear. It could be that incremental increases in content knowledge do not translate into similarly incremental increases in argumentation quality, but there are certain knowledge thresholds that confer noticeable increases in argumentation quality. In discussing the applicability of localized and general knowledge, Perkins and Salomon (1989) talk about the fact that individuals must be aware of some basic knowledge before they engage in reasoning or behavior. They analogize to the game of chess: "one can't play chess without knowing the rules of the game" (Perkins & Salomon, 1989, p. 17). Likewise, people cannot engage in argumentation regarding genetic engineering without understanding basic vocabulary related to human heredity. We might call this fundamental knowledge "rules of the game knowledge". "Rules of the game knowledge" serves as an initial threshold. We would expect that individuals lacking this basic knowledge would have difficulty reading and understanding the kind of prompts used to set up the interviews in the current study. Without understanding even the most basic features of the issues, these individuals would necessarily struggle to articulate reasonable arguments. With the acquisition of basic "rules of the game knowledge", we would expect a significant increase in argumentation quality. Most high school biology curricula, with their general overviews of genetics, should ideally provide most students with "rules of the game knowledge" relative to genetic engineering.

"Rules of the game knowledge" serves as the first knowledge threshold, but there may exist a second threshold based on an advanced repertoire of knowledge not typically associated with most high school science curricula. This second threshold may mark a difference in how individuals organize, interpret, and represent information in a manner similar to the distinctions observed in experts and novices (Bransford, Brown, & Cocking, 1999). "Advanced knowledge" may enable the same kind of jump in argumentation quality that "rules of the game knowledge" conferred. Figure 2 presents a graphic representation of this model. The horizontal axis, which

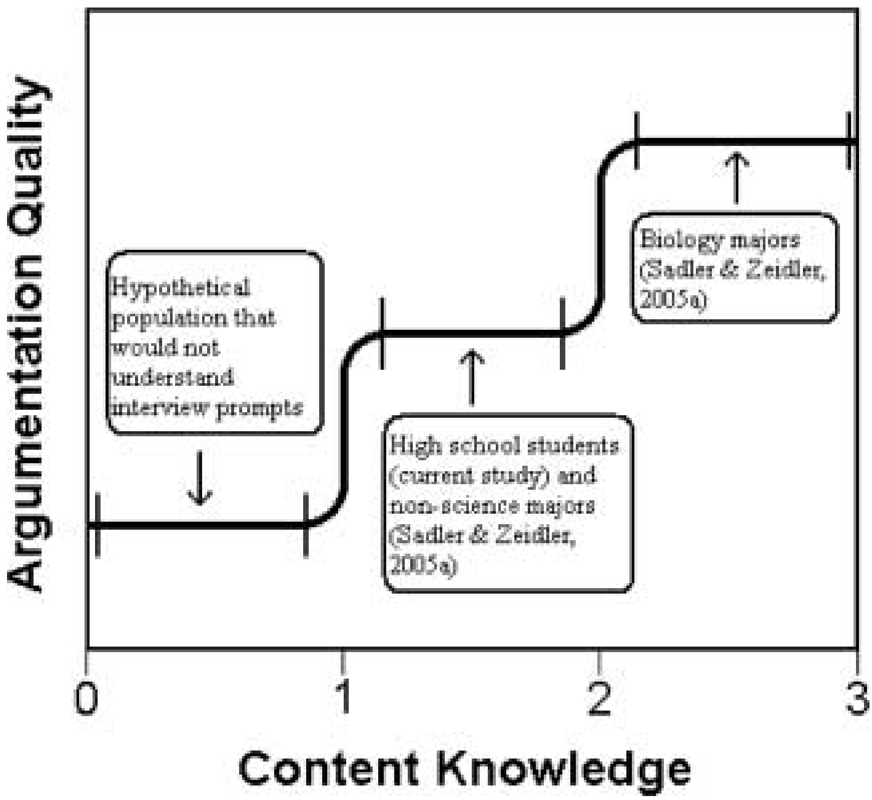

Figure 2. Graphic representation of the "Threshold Model of Content Knowledge Transfer". *Note*: Numbers on the content knowledge scale represent the following: 0, little or no knowledge; 1, "rules of the game knowledge"; 2, "advanced knowledge"; and 3, knowledge expected of a professional or expert

represents content knowledge, is labeled with several numbers indicating qualitatively different levels of conceptual understanding. The “1” represents “rules of the game knowledge”; individuals at or above this point have a general understanding of the most fundamental concepts underlying an issue. An individual would need “rules of the game knowledge” to understand the interview prompts provided. The “2” represents “advanced knowledge”; individuals at or above this point possess an understanding of pertinent science concepts beyond what we would reasonably expect of high school students. “Advanced knowledge” might be commensurate with what individuals majoring in the discipline would understand. Given the issues under consideration in this study, we would expect college biology majors with extensive coursework or experience in genetics to possess “advanced knowledge”.

The evidence presented as a part of this study alone cannot substantiate the “Threshold Model of Knowledge Transfer” just presented; however, the combined results of this study and Sadler and Zeidler (2005a) provide evidential support. Results of the current study seem to directly contradict the findings of Sadler and Zeidler. Whereas the current study revealed no significant relationship between content knowledge and argumentation skills, Sadler and Zeidler found significant differences in the quality of informal reasoning presented by groups with disparate content knowledge. However, the threshold model accounts for this apparent discrepancy. In the Sadler and Zeidler study, biology majors who had scored very well on the TBGC demonstrated significantly higher quality informal reasoning than non-science majors who performed poorly on the TBGC. Based on comments made in a series of interviews, most of the biology majors in the study knew far more about genetics than the TBGC was able to ascertain. These individuals possessed “advanced knowledge” of genetics. The TBGC was written to assess basic genetics knowledge consistent with what one might learn in high school. It was not designed to discriminate among individuals with advanced genetics knowledge. Scores on the TBGC from participants in the current study ranged from low to high; but whereas the instrument was unable to assess the full scope of Sadler and Zeidler’s biology majors’ content knowledge, high scores on the TBGC in the current study probably represented maximum performance. In other words, even though some individuals from both studies scored high on the TBGC, high-scoring biology majors from the Sadler and Zeidler study probably knew a great deal more about genetics than the high-scoring high school student in the current study. The high-scoring high school students knew more about genetics than their lower scoring peers, and even the science non-majors from Sadler and Zeidler (2005a), but they did not have the “advanced knowledge” necessary to surpass the second threshold.

Some of the participants in the current study scored very low on the TBGC, indicating that they did not know a great deal about genetics. However, as they read the interview prompts, they were free to ask questions, and the interviewer actively sought to support participants as they attempted to make meaning of the genetic engineering issues. Because all of the participants had been exposed to basic genetics concepts in high school biology courses and their understanding of the genetic engineering descriptions and prompts were supported by the interviewer, it is likely that all of these individuals possessed at least "rules of the game knowledge". The high-scoring (on the TBGC) participants probably knew a great deal more about genetics and genetic engineering than "rules of the game knowledge"; however, their knowledge likely did not surpass the "advanced knowledge" threshold. It is likely that all of the participants in the current study had access to knowledge somewhere between "rules of the game knowledge" and "advanced knowledge". According to the "Threshold Model of Knowledge Transfer", we should not expect significant differences in argumentation quality among these individuals.

Of these three interpretations—1, students just do not think to use of content knowledge in the context of SSI; 2, students do not possess adequate context knowledge; and 3, knowledge thresholds—we think some elements of each contributed to the data collected in this study. The fact that participants did not think to apply their content knowledge (or perhaps did not know how their content knowledge applied to the scenarios) may be a characteristic of individuals who possess enough knowledge to understand the rules of the game but not enough to be considered advanced. In addition, an important relationship exists between the second and third interpretations. The second interpretation implies that participants do not have enough context knowledge, whereas the third implies that participants do not have enough content knowledge. Situated accounts of knowing (Brown, Collins, & Duguid, 1989; Greeno, 1998) blur the distinctions between context and content knowledge. This perspective suggests that in order to develop robust understandings of genetics and genetic engineering, learning experiences require meaningful contexts. Understandings of content and context are interdependent.

Morality

The extent to which moral consideration contribute to socioscientific argumentation was another focus of our work. Some authors have suggested that moral considerations necessarily contribute to argumentation in the context of SSI (see Evans, 2002; Zeidler & Keefer, 2003), and several studies have revealed decision-makers' tendencies to actually construe SSI as moral problems (see Bell & Lederman, 2003; Pedretti & Hodson, 1995; Sadler & Zeidler, 2004). Our results support this trend. The qualitative analyses suggest that high school students engaged in discussions of genetic engineering frequently construed the issues under consideration as moral problems. However, quantitative results did not complement this finding. Scores on the DIT were not statistically significantly correlated with argumentation quality. We believe that the discrepancy can be accounted for by the nature of the DIT. This instrument is based on the neo-Kohlbergian paradigm of morality, which focuses on the application of abstract moral principles such as justice, beneficence, and non-malevolence (Rest et al., 1999). It is probable that this abstract perspective on morality fails to describe the kind of personal morality invoked by the scenarios presented in this study. Rest et al. call this more personally relevant perspective "micromorality", and distinguish it from "macromorality", which subsumes traditional deonotological perspectives including neo-Kohlbergian morality. The neo-Kohlbergian paradigm with its emphasis on abstract moral principles does not adequately account for the type of moral reasoning and emotion involved in socioscientific decision-making (Sadler, 2004c). Therefore, correlations between socioscientific argumentation and the DIT necessarily underestimate possible relationships between argumentation and moral considerations.

Implications

An important implication of this research for educators is that we cannot assume that increases in content knowledge necessarily improve the quality of argumentation among our students. At least one interpretation of the results, consistent with the knowledge threshold model presented, suggests that, beyond a very basic understanding of heredity, students would need to acquire a substantial body of content knowledge before that knowledge would significantly affect argumentation quality. Instruction this extensive may not be possible in typical high schools given constraints of class time, student interests, and pressures to cover a variety of topics. The "inch deep, mile wide" curricula that may result from the growing reliance on standards will certainly not encourage the development of the kind of advanced knowledge needed for the highest quality argumentation.

How, then, should educators approach the challenge of SSI in the curriculum? Should we resign ourselves to avoiding the issues altogether in high schools given the fact that it remains unlikely that most high school students will gain "advanced knowledge"? Content knowledge is only one potential problem; the inherent morality of SSI presents entirely different challenges to the science teacher (Levinson, 2003). However, we believe SSI must be a part of science education because the ability to negotiate SSI and engage in argumentation concerning these issues is fundamental to our view of scientific literacy. Regardless of the classroom difficulties SSI present, they should be essential elements of a student' education in science.

With these concerns in mind, we have two suggestions, stemming from this research and the previous work that served as a basis for the current study, for science educators who share the goal of preparing students to deal with complex scientific issues with social implications. Firstly, student reasoning and argumentation could be enhanced by a more explicit focus on SSI contexts and not just the underlying science concepts and facts. If we want to help students thoughtfully participate in the public debate surrounding SSI, we need to provide opportunities to consider basic science *and* its applications. A series of studies conducted in Europe, Asia, and Australia (Chen & Raffan, 1999; Dawson & Schibeci, 2003; Gunter, Kinderlerer, & Beyleveld, 1998) highlight the trend revealed in the current research: on average, students possess inadequately low understandings of and exposure to SSI contexts. In the three studies just mentioned, approximately 40% of the high school students sampled did not know what biotechnology was, and even when described only about one-third of the samples could cite an example of biotechnology. If we want students to be better prepared to deal with SSI, they need more exposure to common issues such as biotechnology and genetic engineering in the classroom. Secondly, argumentation skills themselves should also become an educational focus. Zohar and Nemet (2002) found that genetics instruction coupled with training in argumentation produced positive effects on argumentation patterns in the context of genetic engineering issues. These data coupled with our own findings suggest that content knowledge alone does not necessarily result in improved argumentation. Instruction that focuses on argument structure (i.e., positions, counter-positions, and rebuttals), the status of evidence, fallacious reasoning, and the consistency/coherence of claims could be valuable additions to the science curricula.

We realize that these suggestions are not unproblematic considering the current demands on science curricula and teachers. However, if we maintain a vision of scientific literacy, to which the negotiation of SSI is central, then strategies for enhancing student reasoning and argumentation in the context of SSI must be undertaken. To provide the classroom support needed for this endeavor, the research community must assume the responsibility of researching pedagogical approaches that may meet the needs of students and teachers. We, as researchers, need to direct attention to effective means of helping students understand the content and context of SSI as well as the argumentation skills necessary for communicating positions, concerns, and rationales.

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