A Threshold Model of Content Knowledge Transfer for Socioscientific Argumentation

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ABSTRACT: This study explores how individuals make use of scientific content knowledge for socioscientific argumentation. More specifically, this mixed-methods study investigates how learners apply genetics content knowledge as they justify claims relative to genetic engineering. Interviews are conducted with 45 participants, representing three distinct groups: high school students with variable genetics knowledge, college nonscience majors with little genetics knowledge, and college science majors with advanced genetics knowledge. During the interviews, participants advance positions concerning three scenarios dealing with gene therapy and cloning. Arguments are assessed in terms of the number of justifications offered as well as justification quality, based on a five-point rubric. Multivariate analysis of variance results indicate that college science majors outperformed the other groups in terms of justification quality and frequency. Argumentation does not differ among nonscience majors or high school students. Follow-up qualitative analyses of interview responses suggest that all three groups tend to focus on similar, sociomoral themes as they negotiate socially complex, genetic engineering issues, but that the science majors frequently reference specific science content knowledge in the justification of their claims. Results support the Threshold Model of Content Knowledge Transfer, which proposes two knowledge thresholds around which argumentation quality can reasonably be expected to increase. Research and educational implications of these findings are discussed.

INTRODUCTION

Two overlapping areas of interest have emerged over the last several years as significant themes in science education research: socioscientific issues (e.g., Oulton, Dillon, & Grace, 2004; Sadler, 2004; Zeidler, 2003) and argumentation (e.g., Kelly & Takao, 2002; Osborne, Erduran, & Simon, 2004; Sandoval & Millwood, 2005). Socioscientific issues...
(SSI) represent complex social dilemmas based on applications of scientific principles and practice. Argumentation circumscribes the discursive practices of science and includes the articulation and justification of claims, the contemplation of counterpositions and evidence, and the social negotiation of data and theories. This study explores high school and college student argumentation in the context of SSI, i.e., socioscientific argumentation. Of particular interest is how individuals use scientific content knowledge as they make and justify claims relative to genetic engineering scenarios. Our work explores whether and how students transfer genetics understandings to argumentation contexts centered on biotechnology and society.

THEORETICAL FRAMEWORK
Socioscientific Issues

The SSI movement has advanced a vision of school science that prioritizes student experiences with contemporary social dilemmas related to or based on science. The underlying idea is that school science should reflect the dynamic interactions of science and society with emphases on not only the science behind contemporary issues confronting all citizens but also the associated social, political, economic, and moral challenges. Research findings suggest that individuals are naturally inclined to consider these sociocultural factors when confronted with SSI (Sadler & Zeidler, 2005a). Teacher efforts to distill “the science” from SSI to the exclusion of other contextual factors encourage the compartmentalization of school science. When isolated in this fashion, school science experiences likely have little influence on student behaviors and practices in response to the kinds of authentic problems individuals face as participants of modern democracies (Sadler, Zeidler, & Chambers, 2004; Zeidler, Walker, Ackett, & Simmons, 2002). Therefore, the SSI movement has advocated situating real-world issues in science classrooms as platforms for learner exploration of traditional science content along with the social realities of scientific practice.

Argumentation

Argumentation has also gained renewed prominence as a theme and approach for classroom experiences as well as a focus for educational research. At least some of the interest in argumentation is due to the adoption of situated perspectives on what it means to know and learn (Brown, Collins, & Duguid, 1989; Greeno, 1998). This theoretical shift transforms idealized notions of science classrooms from repositories of science facts to environments that foster legitimate peripheral participation (Lave & Wenger, 1991) among learners. In these environments, learners do not just learn about science or complete science activities; they become more broadly enculturated into science and come to appropriate scientific practices as a part of their own identities. While scientific practice may include conceptual understanding and skills, commonly promoted in science such as observation and measurement, it also includes meta-level understandings of the nature and standards of scientific inquiry (Kuhn, Black, Keselman, & Kaplan, 2000) as well as the discursive practices upon which the social enterprise of science is built. Given this perspective, argumentation is central to the practice of science and, by extension, should assume an equally central role in science classrooms (Duschl & Osborne, 2002).

Toulmin’s (1958) philosophical exploration of argumentation has had profound impacts on the study and assessment of argumentation, particularly with respect to science education. Toulmin’s Argument Pattern (TAP) provides a framework for analyzing argument structure and specifies features such as claims, data, warrants, backings, and rebuttals.
TAP has served as the primary analytic tool for many (probably most) studies that have sought to evaluate the quality of arguments offered by students in scientific and socioscientific contexts (e.g., Jiménez-Aleixandre, Rodríguez, & Duschl, 2000; Osborne et al., 2004; Zohar & Nemet, 2002). Despite its frequent use, TAP presents a number of methodological limitations. Chief among the problems associated with TAP is the ambiguous nature of argument structures identified by TAP (Erduran, Simon, & Osborne, 2004; Kelly, Druker, & Chen, 1998). Distinguishing what counts as data, warrants, and backings can be particularly tricky, leaving the reliability of TAP-based assessment schemes questionable. Some of the most recent advances in the application of TAP to science education (Erduran et al., 2004) have minimized the problems associated with the ambiguity of argument structures by collapsing the most problematic categories (i.e., data, warrants, and backings) and focusing heavily on the emergence of rebuttals. While this approach is certainly powerful for some research contexts, it presents its own methodological limitation in that it can only be applied to group discussions. In some instances, particularly in the current era of scientifically based research, it is necessary to gauge individual student aptitude, epistemic orientation, and progress. While we recognize that argumentation is a socially situated activity, we also believe that individuals may personally appropriate practice and employ elements of that practice in contexts other than its original setting much in the same way that situated knowledge can be transferred (Resnick, Levine, & Teasley, 1991).

**Socioscientific Argumentation**

Patterns of socioscientific argumentation have been investigated in contexts such as human genetic issues (Zohar & Nemet, 2002), local environmental issues (Patronis, Potari, & Spiliotopoulou, 1999), and global warming (Adams, 2002). A common assumption underlying much of this work suggests that learners’ content knowledge related to the SSI under consideration significantly influences argumentation practice (e.g., Dawson & Schibeci, 2003; Patronis et al., 1999; Yang & Anderson, 2003). The idea that individuals rely on their scientific understandings to analyze and justify their positions regarding SSI intuitively appeals to science educators, particularly those of us who conceptualize the purposes of science education as the bridging of science into the lives of students. However, literature from beyond science education, which has dealt more generally with transfer of knowledge (Haskell, 2001), argumentation (Kuhn, 1991), and informal reasoning (Perkins, Farady, & Bushey, 1991), has questioned the presumed link between argumentation and domain-related content knowledge. In the current study, we take up the challenge of exploring relationships between students’ understanding of relevant science concepts and their socioscientific argumentation practices.

Beyond the intuitive appeal of presumed links between content knowledge and argumentation, educators have reason to support this hypothesis. Two fairly recent reports have documented a significant influence of content knowledge in student negotiation of ill-structured problems related to meiosis (Wynne, Stewart, & Passmore, 2001) and the spread and treatment of HIV (Keselman, Kaufman, & Patel, 2004). Other findings, more closely aligned with the SSI agenda, also support a link between knowledge and reasoning or argumentation (Hogan, 2002; Tytler, Duggan, & Gott, 2001; Zohar & Nemet, 2002), but the foci of these studies were not directly related to informing these relationships, and the evidence was not particularly strong with regards to this issue (see Sadler, 2004). In Sadler and Zeidler (2005b), we explore how socioscientific argumentation in the context of genetic engineering issues varies across two groups of college students: one group of nonscience majors with naïve understandings of genetics and another group of science majors with well-developed understandings of genetics. We find that while both groups
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rely on similar patterns of reasoning (i.e., both groups reveal comparable tendencies to make use of rationalistic, intuitive, and emotive resources), the science majors demonstrate significantly higher quality argumentation than their peers. This study offers evidence in support of the presumed relationship between content knowledge and socioscientific argumentation, but it also suffers from limitations, which necessarily restricts the applicability of its findings. Sampling is based on participant scores on a genetics knowledge test and a maximum-variation strategy. Although we present qualitative data to support the conclusion that content knowledge is, in fact, one of the factors contributing to differences observed in argumentation, other group level variables may also contribute to the differences.

Threshold Model of Content Knowledge Transfer

In follow-up work (Sadler & Donnelly, in press), we assess socioscientific argumentation from a randomly selected group of high school students with varying levels of genetics content knowledge. Regression analyses suggest no statistically or practically significant relationships between students’ understanding of genetics, as measured by a multiple-choice test of basic genetics concepts, and quality of argumentation, assessed through a mixed-methods approach for the analysis of semistructured interviews. To account for the apparent discrepancies in findings while maintaining the legitimacy of each study, Sadler and Donnelly propose the “Threshold Model of Content Knowledge Transfer.” The threshold model supports the hypothesis that argumentation is related to content knowledge, but the relationship is nonlinear. It postulates at least two knowledge thresholds at which we should expect improvement of argumentation practice. The model is graphically displayed in Figure 1.

The figure’s horizontal axis represents content knowledge and the numbers demarcate qualitatively distinct levels of understanding. The number “1” represents very basic understanding similar to what Perkins and Salomon (1989) referred to as “rules of the game” (p. 17) knowledge. Just as individuals cannot play a game of chess without an

![Figure 1. 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.](image-url)
understanding of the rules, individuals would struggle to engage in meaningful argumentation without the most basic understandings of content. In short, a student cannot support a position relative to gene therapy without knowing what genes are and having basic understandings of heredity. As individuals personally appropriate the most basic concepts and vocabulary, thereby attaining “rules of the game” understanding, we expect to see a demonstrable jump in their argumentation practice. Consistent with work in the area of expert understandings (Bransford, Brown, & Cocking, 1999), the model proposes a second threshold, designated by the number “2” on the horizontal axis, that corresponds to “advanced knowledge.” This level represents understanding commensurate with the experiences of college students majoring in a discipline. According to the model, just as acquisition of rules-of-the-game knowledge confers opportunities to improve argumentation practice, acquisition of advanced knowledge enhances argumentation. Sadler and Donnelly (in press) suggest that the differences in argumentation observed between science majors (with advanced knowledge) and nonscience majors (with rules-of-the-game knowledge) in Sadler and Zeidler (2005b) demonstrate enhancement of argumentation across a threshold.

Although major jumps in argumentation quality occur at the thresholds, relatively little change in argumentation practice is hypothesized between thresholds. For instance, the model predicts insignificant differences between the argumentation displayed by most individuals whose understanding falls between basic rules-of-the-game knowledge and advanced knowledge. Sadler and Donnelly’s (in press) analyses of the high school student argumentation patterns is consistent with this interpretation. The high school participants, whose knowledge ranged from “rules of the game” to “advanced,” reveal no systematic differences in argumentation practices.

Focus of Research

We contend that the threshold model is consistent with results from the high school sample just described as well as Sadler and Zeidler’s (2005b) work with college students, in which science majors with advanced knowledge performed significantly better on argumentation tasks than their nonscience major peers. However, justification of the model is fairly weak because each of the independent data sets can only account for limited aspects of the model and data across the studies cannot be directly compared. The purpose of the current study is to more rigorously test the threshold model by expanding the range of data available for common analysis. As such, data from both Sadler and Zeidler (2005b) and Sadler and Donnelly (in press) are mined in order to create a common data set from which direct comparisons can be made. This reanalysis addresses the following two research questions:

1. To what extent does the Threshold Model of Content Knowledge Transfer account for differences in socioscientific argumentation among high school and college learners?
2. How does socioscientific argumentation vary among high school and college learners?

The first question relates directly to assumptions underlying the SSI movement. As highlighted earlier in the paper, many educators assume a positive relationship between content knowledge and reasoning and argumentation in the context of SSI. The threshold model supports a relationship but does not affirm a simple linear association. A better understanding of this relationship will inform the design of SSI research and curricula, particularly in terms of the kinds of student-level effects that might be reasonably expected in response to SSI interventions. The second question informs how argumentation varies
among learners at different educational levels. This analysis begins to address the call to better understand the developmental appropriateness of SSI across different educational contexts (Simmons & Zeidler, 2003).

METHODS

Data Sources

In our previous work (Sadler & Donnelly, in press; Sadler & Zeidler, 2005b), we engaged high school and college student participants in semistructured interviews related to genetic engineering issues. Participants were challenged to articulate and defend positions, counterpositions and rebuttals in response to controversial proposals for gene therapy and cloning. The protocols and analyses for each study differed in several ways including the number of scenarios to which participants responded and the nature of follow-up probes used to elicit counterpositions and rebuttals. In order to compare participant responses from both data sets, we selected constant elements across both studies. The procedures outlined below represent those aspects of the original protocols which were shared in both studies and served as the basis for data collection in the current study.

The first author conducted interviews with individual participants in a private office or conference room, and the sessions were audiotaped and transcribed for analysis. Following a quick introduction, the interviewer provided a brief overview of gene therapy, offered students an opportunity to ask questions, and asked participants to read a short scenario describing Huntington’s disease and the use of gene therapy to eliminate the disease. The interviewer then asked the participant what s/he thought about the appropriateness of using gene therapy for this purpose and why s/he held that position. If a participant’s position was unclear, the interviewer asked for clarification or elaboration. This basic interview protocol was used with two additional issues: gene therapy to enhance intelligence and reproductive cloning. As mentioned above, the actual interviews were more extensive, but for the purposes of this report, only those sections of the transcripts which corresponded to these procedures were included in the analysis. Analyses were based on participants’ elaborated positions and justifications relative to three genetic engineering issues.

Samples

Thirty upper division undergraduates from a large university in the Southeastern United States participated in the interviews. Two distinct subsamples made up the overall sample: science majors and nonscience majors. Fifteen science majors, who had performed very well on a test of basic genetics concepts, participated in interviews along with 15 students who had not studied science extensively and who had performed very poorly on the same genetics test. Students were recruited from a variety of courses, including several advanced-level biology and psychology classes. More detailed information regarding sampling procedures and the nature of the test administered are presented in Sadler and Zeidler (2005b).

Forty-eight students from a high school, in the same urban area as the university from which the older participants were sampled, also participated in interviews. These students had completed at least one high school biology course and were recruited from chemistry, physics, anatomy, and marine science classes. The students had taken the genetics test completed by the college participants and displayed an approximately normal distribution of scores. To ensure equivalent group sizes, we randomly selected 15 transcripts for analysis. Another randomly selected set of 15 interviews was also used for developing an argumentation rubric (see below). Demographic information for all three groups investigated as a
THRESHOLD MODEL OF CONTENT KNOWLEDGE TRANSFER

TABLE 1
Demographic Information by Group

<table>
<thead>
<tr>
<th></th>
<th>Science Majors</th>
<th>Nonscience Majors(^a)</th>
<th>High School Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>(N)</td>
<td>15</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Sex</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>8</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Male</td>
<td>7</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Race/ethnicity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asian</td>
<td>2</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Black</td>
<td>0</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Hispanic</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>White</td>
<td>11</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>Average age (SD)</td>
<td>21.4 (1.7)</td>
<td>21.5 (2.4)</td>
<td>16.5 (0.83)</td>
</tr>
<tr>
<td>Average genetics test score (SD)</td>
<td>16.1(^b) (0.92)</td>
<td>5.5(^b) (0.96)</td>
<td>8.3(^b) (3.5)</td>
</tr>
</tbody>
</table>

\(^a\)Data presented in this column are from the 15 participants randomly subsampled from Sadler and Donnelly’s (in press) larger sample (\(n = 48\)).

\(^b\)Maximum score = 18.

Part of this study (i.e., science majors, nonscience majors, and high school students) is presented in Table 1 and a histogram of scores from the genetics test for each of the groups is presented in Figure 2.

Argumentation Assessment

We briefly reviewed the use and limitations of TAP for the assessment of argumentation in the theoretical framework. Like Erduran et al. (2004), we sought to minimize the problems associated with structural analyses of arguments, which require the parsing of claims, warrants, backings, etc. Rather than assessing all argument structures identified by TAP, we chose to focus our analysis on the justification of claims. We made this decision for two reasons. First, the justification of claims is the most basic form of argumentation practice and is critically important. In its simplest form, argumentation involves the presentation of a claim, and the legitimacy of that claim is improved through its justification. Ideally,

![Figure 2](image-url)  
**Figure 2.** Distribution of subsample scores for the test of basic genetics. *Note.* HS = high school; NM = nonscience majors; SM = science majors. Maximum score = 18.
argumentation in socioscientific contexts would involve justifications grounded in scientific data as well as considerations of the social, economic, and moral implications. Second, the combined data set was ideally suited for the analysis of justifications. Whereas the elicitation of counterpositions and rebuttals had not been consistent in the college and high school samples, prompts used to encourage participants to articulate and justify their positions were equivalent.

Responses to each of the three scenarios were analyzed according to justification themes. For instance, a participant may have justified the claim that gene therapy for Huntington’s disease should not be developed by citing a scarceness of resources and invoking religious beliefs opposing the modification of humans. These two justifications would have been analyzed separately. The number of justifications offered in response to a scenario served as the first metric of argumentation practice, but this measure was not used to determine the quality of arguments. To assess the quality of arguments offered, we developed a justification rubric. The rubric’s basic framework was established a priori, and inductive analyses of a small data set, not included in the final analysis, helped refine the rubric and clarify distinctions among levels within the rubric. (For these purposes, we made use of 15 randomly selected interviews from among the 33 high school interviews not used in the primary analysis.) To help establish reliability of the rubric, one third of the transcripts from all three subsamples were randomly selected for examination by both authors. The authors independently identified justification themes raised within an interview and “scored” responses based on the rubric. Interrater consistency, calculated by comparing each author’s scoring results prior to negotiation, exceeded 90% for both the identification of justification themes and assigning justification scores based on the rubric. For the initial discrepancies, our scores were no more than one rubric level off, and we were able to easily reach consensus on the areas of initial disagreement. The first author applied the rubric to the remaining transcripts.

Like most TAP-based assessment schemes, the rubric focused on argument structure, but it was not a structural scheme in the sense that the adequacy of the argument was solely determined by the presence of predetermined structures (e.g., warrants, backings, qualifiers, rebuttals, etc.). Rather than attempting to sort unique elements of an individual’s argument, the rubric was designed to distinguish among arguments based on how the claims advanced were justified. The rubric used to assess the justifications as well as representative interview excerpts for each level of the rubric are presented in Table 2. The lowest level of the rubric described situations in which a participant failed to provide a justification in support of his/her position. In the excerpt exemplifying this level, the participant assented to the use of reproductive cloning but did not support that position with any sort of justification. The next level captured those cases in which a participant provided justification of his/her position but failed to support the justification with any grounds. Grounds, used in this sense, corresponded to a variety of possible supports or details regarding a justification. Statements that would have been classified as data, warrants, or backings in Toulmin’s scheme were considered grounds. In this way, we avoided some of the classification difficulties that have been identified in the application of TAP to scientific and socioscientific argumentation. In the excerpt demonstrating the second level, the participant agreed to the use of gene therapy for Huntington’s disease and justified this position because the treatment could alleviate suffering, but no grounds were offered in support of the justification. The next level captured those cases in which a participant provided justification of his/her position but failed to support the justification with any grounds. Grounds, used in this sense, corresponded to a variety of possible supports or details regarding a justification. Statements that would have been classified as data, warrants, or backings in Toulmin’s scheme were considered grounds. In this way, we avoided some of the classification difficulties that have been identified in the application of TAP to scientific and socioscientific argumentation. In the excerpt demonstrating the second level, the participant agreed to the use of gene therapy for Huntington’s disease and justified this position because the treatment could alleviate suffering, but no grounds were offered in support of the justification. The third and fourth levels of the rubric required justification with grounds. The distinction between the two levels was established by the extent to which justifications were grounded. In level three responses, a justification was supported relatively simply by a single ground. Level four responses demonstrated more elaborate and well-supported grounds. In the level three excerpt, the participant justified his/her rejection of cloning on the basis of a moral or religious objection. The participant provided a single ground for the justification by...
### TABLE 2
Argumentation Quality Rubric

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
<th>Excerpt</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No justification</td>
<td><em>In response to the reproductive cloning scenario:</em> “Yes, I think so [reproductive cloning should be developed].”</td>
</tr>
<tr>
<td>1</td>
<td>Justification with no grounds</td>
<td><em>In response to the gene therapy for Huntington’s disease scenario:</em> “If they can stop someone from suffering, then sure.”</td>
</tr>
<tr>
<td>2</td>
<td>Justification with simple grounds</td>
<td><em>In response to the reproductive cloning scenario:</em> “I don’t think it’s 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 mean, I think you shouldn’t tamper with it.”</td>
</tr>
<tr>
<td>3</td>
<td>Justification with elaborated grounds</td>
<td><em>In response to the gene therapy for intelligence scenario:</em> “They will develop a dichotomy even more so than we see now with the rich and poor. Now we will have the smart vs. the stupid or those who can afford this procedure and those who cannot. And that will create all kinds of sociological problems. I think that is meddling too much.”</td>
</tr>
<tr>
<td>4</td>
<td>Justification with elaborated grounds and a counterposition</td>
<td><em>In response to the gene therapy for Huntington’s Disease scenario:</em> “I think that gene therapy, it should be actually used very sparingly because what it does is narrows the diversity—like everyone gets the good copy now so that is not necessarily good because then we do not have a backup for anything. But in cases like this, where the only cure would be replacing the actual gene, then it could be beneficial . . . If there are no other treatments for it, that would be the only way that I would support using gene therapy for something like that. But I think all other means should be exhausted before we start messing with someone’s genes.”</td>
</tr>
</tbody>
</table>

claiming that if God wanted an individual to have a child, the individual would be able to do so. In contrast, the level four excerpt revealed more elaborate grounds by drawing an analogy to current disparities between socioeconomic classes and presenting a prediction of the consequences of gene therapy for intelligence. The highest level of the rubric was reserved for participants who not only were able to provide grounded justifications but also recognized positions or evidence contradictory to their own. The ability to consider an issue from a perspective other than one’s own or attend to counterevidence is generally considered an important but difficult element of argumentation practice (Erduran et al., 2004; Kuhn, 1991). The excerpt provided revealed this trend in that despite his/her support for gene therapy for Huntington’s disease, s/he expressed extreme caution due to the gravity of germ-line manipulations.
In order to compare the quality of arguments offered by participants from the three subsamples, we performed a multivariate analysis of variance (MANOVA) using the group (high school, nonscience major, science major) as the independent variable and the number of justifications (summed across all three scenarios) and the argumentation quality scores (summed across all three scenarios) as the dependent variables. When participants offered multiple justification themes in response to a single scenario, each theme was assessed independently and the highest score was used in the summation.

**Qualitative Analysis**

In addition to the mixed-methods approach for assessing argument quality, we employed qualitative analyses to explore the patterns of justifications offered in response to the socio-scientific scenarios used. This work was consistent with inductive data analysis (Lincoln & Guba, 1985) and the constant comparative method (Strauss & Corbin, 1998). While we did not impose a priori taxonomies or frameworks on the data, we searched for emergent patterns that characterized the kinds of conceptual resources that participants relied on to justify their decisions. Given the focus of our research, we were particularly interested in how participants used science content knowledge in the justification of positions and how the basis of participants’ justifications varied or were similar among the three subsamples. To initiate this work, both authors independently examined one third of the interview transcripts from each subsample and established some tentative patterns. After negotiating an emergent taxonomy reflective of themes derived from both of the researchers’ insights, the second author completed the qualitative analyses on the remaining data set. Both authors thoroughly reviewed patterns that were not evident in the original taxonomy.

Consistent with other qualitative researchers (Eisner, 1998; Lincoln & Guba, 1985), we have chosen not to include frequency counts for the qualitative categories. Our goal is to present a picture of argumentation tendencies without suggesting generalizability to other samples in terms of frequencies or proportions. The trends identified describe how these participants responded to SSI and may be indicative of thematic patterns among the broader populations from which the samples were taken. While individual participants’ responses to each scenario presented unique elements, we sought to make sense of the particularities by searching for emergent commonalities. Only those themes which were demonstrated by a minimum of five participants are included in this presentation.

**RESULTS**

**Argumentation Assessment**

Participants from all of the subgroups, high school students, nonscience majors, and science majors demonstrated variability with respect to the quality of their justifications offered in response to the socioscientific scenarios. The distributions of individual scores across all three scenarios appeared to vary by group. A histogram of scores by group is presented in Figure 3. Because each of the 15 participants from each group responded to three scenarios, a single group’s distribution accounts for 45 scores. The distribution of science majors’ scores was higher on the rubric relative to both the high school and nonscience major score distributions.

Participant scores for argumentation quality (an individual’s highest justification score based on the rubric to each scenario summed across all three scenarios) could have theoretically ranged from 0 to 12. Actual score ranges were 5–11 for the science majors and
The means were 7.93 (SD = 2.22) for science majors, 4.20 (SD = 1.66) for nonscience majors, and 3.53 (SD = 1.85) for high school students. The distribution for number of justification themes articulated (summed across all three scenarios) followed a similar pattern with ranges of 3–10 for science majors (mean = 5.07, SD = 1.83), 1–6 for nonscience majors (mean = 3.33, SD = 1.40), and 1–5 for high school students (mean = 3.13, SD = 0.91).

It was determined that a MANOVA analysis was appropriate for our study because our sample met the assumptions for multivariate normality ($b_{1,p} = 2.41, 0.17, and 1.91; b_{2,p} = 7.36, 6.12, and 9.22$) for science majors, nonscience majors, and high school students, respectively. Equal sample sizes between the three groups assured robustness to possible violations of the equal covariance assumption, while the process of data collection led to independence between participants.

The MANOVA analysis using group (high school, nonscience major, or science major) as the independent variable and argumentation score and number of justification themes as the dependent variables revealed a statistically significant difference among the three groups [Wilks’ $\Lambda = 0.466, F (4, 82) = 9.54, p < 0.0001$]. Follow-up Tukey’s HSD analysis with an overall alpha of 0.05 revealed that both argumentation scores and number of justification themes were significantly higher for science majors than nonscience majors or high school students. Argumentation scores and number of justification themes did not differ significantly between nonscience major college students and high school students.

While the differences among the groups were statistically significant, they were also practically significant. The mean scores for argumentation quality for nonscience majors and high school students (4.20 and 3.53, respectively) suggest that over the three scenarios, participants averaged 1–2 on the justification rubric. In contrast, the science majors averaged 2–3. This suggested that whereas high school and nonscience major participants tended to offer ungrounded or weakly grounded justifications, the science majors tended to offer more strongly grounded justifications. Likewise, the high school and nonscience majors averaged approximately 1 justification per scenario, the science majors averaged 1.7 justifications per scenario. These differences in practice were significant from practical as well as statistical perspectives.
Qualitative Analyses

Qualitative analyses complemented the MANOVA results in that the science majors displayed very different patterns in terms of how they used specific biological content knowledge to support their positions. Whereas only one participant, a high school student, from among the nonscience majors and high school groups referred to specific content knowledge, most (13 of 15) of the science majors explicitly referenced biological content in the justification of their claims. Most of these participants used content knowledge in response to multiple scenarios. The manners in which science majors used content knowledge varied across individuals and scenarios. Some participants referenced their understanding of human genetics and gene therapy. This pattern is displayed in the excerpt below:

Germ line [gene therapy] is really scary as is cloning and the genome project . . . Germ line is genetically altering, and it [the gene] carries through to your offspring and you create more and more and more.

Participants also demonstrated an awareness and understanding of existing work in the area of cloning:

In the beginning stages, it [cloning] will have problems just like anything else. They had to do hundreds of trials with all the things that they did clone before they got one right. Is it worth the risk of bringing a child into the world who is deformed?

Others talked about the scenarios in terms of how medical science had dealt with other diseases:

[Huntington's disease] is a very painful, debilitating disease—if we have the capacity to eliminate it—we have eliminated smallpox and things like that that have affected us. What is the difference between a biotic disease and one that is genetic? If we can eliminate one, why shouldn't we eliminate the other?

The most frequent class of responses that demonstrated biological knowledge was based on evolutionary considerations. These arguments tended to focus on how making genetic modifications could disrupt patterns of natural selection and alter the trajectory of human evolution. A response exemplifying this pattern follows.

The genetic similarities [resulting from genetic engineering] could be bad in terms of from an evolutionary standpoint. The same people could be affected by the same disease. You need some kind of genetic variation in the population to ensure some kind of stability.

While the use of content knowledge varied among the groups, the basic arguments offered by all three groups tended to focus on sociomoral aspects of SSI. The major themes that served as the basis for claim justifications were invoked by participants in all of the groups in similar ways to support their socioscientific argumentation. These themes and excerpts indicative of each are presented in Table 3. The sections below briefly detail each theme.

Religious/Social Norms. The most ubiquitous theme used by participants from all three groups in response to all three of the scenarios related to participant perceptions of religious and social norms. Individuals displaying this theme tended to reject the use of a
<table>
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<th>Theme</th>
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<tr>
<td>Religious/social</td>
<td>Participants did not support the use of a genetic technology because it violated religious, social, or moral norms.</td>
<td>“No, only because it [gene therapy] is messing with—I believe in God … It is messing with God and all the stuff God gives to you—like, what he want you to have.”</td>
<td>Frequently invoked by members of all groups in response to all scenarios.</td>
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<td>Consequences</td>
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<td>Pro</td>
<td>Participants supported the use of a genetic technology because of its assumed positive impacts on the quality of life.</td>
<td>“They can help a person live longer instead of until like thirty-five years of age. It [gene therapy for Huntington’s disease] is not doing anything to hurt the person; it is just trying to help the person.”</td>
<td>Used across all scenarios but most prevalent in the HD scenario.</td>
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<tr>
<td>Con</td>
<td>Participants did not support the use of a genetic technology based on the potential negative consequences of its application.</td>
<td>“In the beginning stages it [reproductive cloning] will have problems just like anything else. They had to do hundreds of trials with all the things that they did clone before they got one right. Is it worth the risk of bringing a child into the world who is deformed? I do not think so at this point.”</td>
<td>Used across all scenarios but most prevalent in the IN scenario.</td>
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<td>Limited options</td>
<td>Participants supported the use of a genetic technology because it was the only option for a desired outcome.</td>
<td>“I think they [parents] should [try reproductive cloning] because there is no other option [for them to have their own child].”</td>
<td>Used across all scenarios but most prevalent in the RC scenario.</td>
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<td>Trivialization</td>
<td>Participants trivialized potential outcomes of the genetic technology and, therefore, did not support its use.</td>
<td>“I guess some people are smarter than others, but it comes with how much education you have, how much you like school, how much you learn … You get smarter as the years go on.”</td>
<td>Used frequently in response to the IN scenario and sparingly in response to the RC scenario.</td>
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<tr>
<td>Equity</td>
<td>Participants did not support the use of a genetic technology because it would establish new sources of social inequity.</td>
<td>“I do not think that it is fair that some people who maybe have more money can go out and get this [gene therapy for intelligence] done and then be smarter than other people.”</td>
<td>Discussed by relatively few participants.</td>
</tr>
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</table>
particular technology because the process or intent violated their religious, social, or moral convictions. Participants with these responses suggested that gene therapy or cloning was “socially taboo,” “playing God,” or “morally wrong.” It should be noted that we are not equating religion, social influences, and morality; however, the nature of participant responses suggested a similar pattern of argumentation. In essence, participants invoking this justification rejected a genetic engineering practice because it conflicted with a personal sense of right versus wrong.

**Consequences.** Participants also frequently based their justifications on the perceived consequences of a genetic technology. These responses, which were demonstrated by members of all three groups, tended to focus either on assumed positive impacts or on potential negative consequences. Justifications based on the positive impacts of genetic engineering highlighted the alleviation of suffering, saving lives, and improving the overall quality of human life. This pattern was evidenced in response to all scenarios, but it was very frequently used in the Huntington’s disease scenario. Justifications based on negative consequences highlighted the potential for the technology to create significant problems. This theme also emerged across all scenarios, but it was particularly prevalent in responses to the gene therapy for intelligence scenario. Some of the problems were directly related to the potential patients such as increased chances of death or deformity. Other concerns included the misuse of genetic engineering for creating “designer babies” or “superhuman soldiers.” A final category of negative consequences related to how application of technology could alter an existing social order. Several participants were concerned that altering genetics, especially in the case of intelligence, could disrupt socioeconomic structures. Many asked questions like, “If everyone is smart, who is going to flip burgers or clean the floors?”

**Limited Options.** Several participants justified their support of a position because they recognized that the situation presented limited options. In these cases, participants implicitly suggested that genetic engineering was acceptable only because it was one of few (or the only) option available for a desired outcome. They reasoned that the ends justified the means. This theme emerged in response to all scenarios but was most frequent for the reproductive cloning scenario.

**Trivialization.** A relatively frequent trend for the intelligence gene therapy scenario was the trivialization of the proposed procedure and outcome. Participants from all three groups expressed skepticism related to the possibility of altering a gene for intelligence, and questioned the need to do so even if it were possible. A common response was that intelligence could be enhanced through schooling, studying, or tutoring, and so complicated procedures such as genetic engineering should not be used. This pattern of trivializing the scenario also emerged, but with much less frequency, in the discussion of reproductive cloning. Participants displaying this theme suggested that the procedure’s result did not justify its use.

**Equity.** The final theme emerged in transcripts from all three groups, but it was not discussed frequently in any of the groups. A relatively small number of participants expressed concern regarding the equitable application of genetic technologies. They tended not to support the development of gene therapy and reproductive cloning because of barriers to access by already disadvantaged segments of the population. They saw genetic engineering as another source of social inequity and were apprehensive about the potential to create new class divisions: genetic haves versus genetic have-nots.
DISCUSSION

In this investigation, we sought to empirically test the Threshold Model of Content Knowledge Transfer (presented in Figure 1) as a theoretical model to account for the interaction of socioscientific argumentation practice and science content knowledge. Previous findings confirmed that large differences in genetics content knowledge (ranging between rules-of-the-game knowledge and advanced knowledge) within the high school sample were not associated with differences in argumentation practice (Sadler & Donnelly, in press). However, the groups of science majors and nonscience majors differed significantly both in terms of argumentation practice and genetics knowledge (Sadler & Zeidler, 2005b). The current reanalysis of these data sets enabled examination of how the two college samples compared to the high school sample. As a group, the high school students demonstrated a wider range of and more well-developed knowledge than the nonscience majors and less well-developed knowledge than the science majors. If a linear model of content knowledge transfer was more appropriate than the threshold model proposed, then we might have expected to observe significant differences in argumentation quality among all three groups with the high school sample falling between the two college samples. However, the results were consistent with predictions from the threshold model: science majors displayed higher quality argumentation than the other groups, and the nonscience majors and high school students did not differ significantly in terms of their argumentation quality.

Alternatively, we might have reasonably hypothesized that the nonscience majors should outperform the high school students because they were older, had attended several years of college, and, therefore, would be advanced developmentally and most likely have richer life experiences. However, the results do not support an interpretation that suggests developmental differences underlying distinctions in socioscientific argumentation quality, at least with respect to the genetic engineering issues explored here.

The qualitative analysis sheds additional light on how socioscientific argumentation practices vary among the three groups. The science majors were the only group (with the exception of one high school participant) to consistently make explicit reference to science content knowledge. Otherwise, the groups demonstrated very similar trends in terms of how they justified their arguments. These results suggest that the three groups were not thinking about the issues in fundamentally different manners. Participants from across all three groups perceived similar problems and promise associated with the proposed genetic technologies, but the science majors were more adept at bolstering their arguments with specific science knowledge.

These results foreground an important issue for socioscientific argumentation. This study has been carefully delimited to focus on the role of content knowledge in the justification of claims and has not dealt directly with the question of how science content is involved in actual decision-making processes. Most evidence amassed over the last decade in the area of SSI (Bell & Lederman, 2003; Dawson & Taylor, 1999; Grace & Ratcliffe, 2002; Levinson, 2004; Ratcliffe, 1997; Sadler & Zeidler, 2004) suggests that socioscientific decision-making processes are primarily guided by sociomoral factors. If this is the case, then science content likely contributes minimally to the actual decisions individuals make in socioscientific contexts. However, research presented as a part of this study suggests that science content knowledge can affect the manner in which individuals defend and justify their positions.

While the analyses presented herein can identify patterns and are consistent with the proposed theoretical model, they obviously cannot answer the question of why differences exist among the groups. Because of the common genetics assessment completed by all participants, we know that genetics content knowledge varies significantly among the three groups, but we do not know how the groups may vary in other ways. For example, in addition
to more sophisticated knowledge structures relative to genetics, the science majors may have also possessed more positive attitudes about science issues. Science majors could also reasonably be expected to have had more opportunities to discuss genetic engineering than members of the other groups sampled. Both of these variables could affect argumentation practices. While we cannot rule these variables out as contributing factors, the qualitative analyses of responses presented in previous reports (Sadler & Donnelly, in press; Sadler & Zeidler, 2005b) lend support to the conclusion that content knowledge (or lack of content knowledge) contributes to the quantitative patterns that have emerged.

This still leaves the question of how or why differences in argumentation quality exist. We believe the results of this work support Haskell’s (2001) interpretations of knowledge base and transfer. Haskell suggests that in order for transfer to occur, learners must possess a knowledge base that is significant in terms of depth, breadth, and organization. In other words, learners must have well-developed schema in order to transfer knowledge (Sadler & Donnelly, in press; Sadler & Zeidler, 2005b). Our results are consistent with the conclusion that the science majors not only had learned basic genetics concepts but also had developed genetics schema robust enough to contribute to their consideration of complex, social issues related to genetic engineering. Some of the high school students had learned genetics concepts as evidenced by their performance on the genetics test, but their schema were not robust enough to meaningfully contribute to their deliberations regarding the SSI.

**IMPLICATIONS**

Any implications drawn from this research must be considered in light of two important limitations. (1) Group variables other than science content knowledge (e.g., interest and issue exposure) may have also contributed to the patterns observed and (2) this research focused specifically on genetic engineering issues. Socioscientific argumentation patterns may vary in vastly different contexts. However, if the threshold model endures continued empirical testing, its implications present daunting challenges for today’s science educators. Educators with progressive notions of scientific literacy suggest that science classrooms should become forums for the discussion of SSI (Driver, Newton, & Osborne, 2000; Hodson, 2003; Zeidler, Sadler, Simmons, & Howes, 2005). These authors, and others with similar commitments including ourselves, have suggested that promoting informed democratic participation should be part of the mission for science education. The findings of the current study provide a stark backdrop against which these idealistic goals are highlighted. The results suggest that students would require a sophisticated and well-organized body of knowledge to have meaningful effects on their practices relative to SSI in order to transform science education in a manner consistent with the vision identified above. While few would object to student development of in-depth knowledge in principle, the realities of modern schools suggests that this may be very hard to achieve and only at the expense of other goals. This situation highlights the ongoing tension between the breadth and depth of the science curriculum (Davies, 2004; Hodson, 2003; Kolstø, 2001; Zeidler, 2003).

If SSI education is positioned as a means of improving student abilities to engage in discourse related to authentic science and society issues, we perceive two reasonable conclusions that can be drawn from the findings presented herein. (1) Abandon efforts to infuse SSI in secondary science classrooms because it is unlikely that students have or can develop sophisticated knowledge structures associated with the kinds of argumentation patterns displayed by the science majors. Instructional time and resources, which are always limited and usually scarce, may be better allocated with goals more in line with traditional notions of science education. (2) Fully embrace SSI as contexts for science learning and commit the instructional time and resources necessary for students to develop expertise in science.
content and socioscientific applications. If educators really want to enhance student practice relative to SSI, then they must be willing to take their students beyond simple understandings of content. Students require opportunities to develop deep understandings of science and experiences that encourage meaningful contextualization of this knowledge. We believe that SSI can actually serve as vehicles for this meaningful contextualization. In our view of knowing and learning, all understanding is contextualized (Barab & Plucker, 2002). Unfortunately, much of what is learned in science classrooms is contextualized in such a way that it becomes fully disarticulated from practice beyond the confines of the classroom. SSI may be a means of bridging school experiences with how students participate in the real world (Zeidler et al., 2002). It is no secret that we favor the adoption of the second conclusion, but we readily admit that a great deal of work exists before a proposal such as this can be actualized. We see socioscientific and argumentation research which can directly inform classroom practices and teacher education (Osborne et al., 2004) as a critically important aspect of the science education agenda.

REFERENCES


SADLER AND FOWLER


