

SOCIOSCIENTIFIC ISSUES, ARGUMENTATION AND CONCEPTUAL UNDERSTANDING IN HIGH SCHOOL GENETICS

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Abstract

The purpose of this research was to explore the impact of classroom argumentation about socio-scientific issues on high school students': 1. argumentation skills; 2. informal reasoning; and, 3, understanding of genetics. The research design was a multiple case study conducted in three schools. Each case study had a quasi-experiment embedded in the design with an intervention where the teachers embedded argumentation in the genetics course. Experimental classes in each case study implemented the intervention and comparison classes did not implement the intervention. Data collection included a pre-post-instruction survey, classroom observations, and teacher and student interviews. The results indicated that for all three cases the students who participated in the classroom argumentation improved on average significantly better than students who did not participate in classroom argumentation in argumentation skills, informal reasoning and, for two of the three case studies, improved significantly more in genetics understanding.

Introduction

It is essential that high school students have the opportunity to be involved in cutting edge debate about science topics that are of relevance and importance to them and the society in which they live (Driver, Newton & Osborne, 2000). They should be able to voice their well-informed opinions based on sound scientific understandings, demonstrate logical patterns of reasoning and support their arguments with scientific evidence (Sadler & Zeidler, 2005a; 2005b). Underpinning this rhetoric is the assumption that there is a reciprocal and positive relationship between the process of argumentation and student understanding of science (Sadler, & Fowler, 2006). It is assumed that student involvement in relevant, real-world argumentation is likely to contribute to understanding. In turn, it is assumed that an understanding of science is essential for students to develop quality arguments.

The term 'argumentation' is used to refer to a process of debate and structured discussion to reason about problems. Toulmin (1958) developed a model that can be used to teach students (and their teachers) the skills of argumentation and to analyze or evaluate students' argumentation about socioscientific issues. A review of research related to argumentation in science education (Sadler, 2004) revealed that the interaction between conceptual understanding and argumentation is by no means clear or straightforward. Some studies that were reviewed showed a positive relationship between reasoning and conceptual understanding while others did not. These studies, Sadler argued, provide confounding information with regard to questions about whether students in high school science classrooms can engage in meaningful argumentation about socioscientific issues, whether this process improves their understanding of the science content under consideration and, conversely, what degree of understanding is adequate for participation in the process of argumentation?

Socioscientific issues are scientific topics where individuals and groups within our society hold a range of conflicting (sometimes mutually exclusive) viewpoints. Decisions about these issues may have social, ethical, political and economic implications. Young people need to be informed, not only about the practical applications of science, but they need to be aware of the complexity of the issues so that they can become informed decision makers in the future. Examples of socioscientific issues that are likely to impact on the lives of young people now, and in the future, include climate change, sustainable development, food and energy resources, health care allocation and population control. On a personal level young people need to be able to make informed choices by evaluating the risks and benefits of using mobile phones, reproductive control and eating genetically modified foods.

Rationale

The purpose of this research was to explore the interaction between high school students' argumentation skills and informal reasoning about a socioscientific issue and conceptual understanding of genetics. Genetics education was selected as the context in this study for three reasons. First, advances in the field of genetics have led to concerns about some applications in our society. Socioscientific issues related to genetics include the production and consumption of genetically modified (GM) foods, the development of 'designer babies' or 'saviour siblings' where pre-implantation genetic testing is used to select embryos free of particular genetic disorders, and genetic susceptibility testing for insurance and employment purposes. The second reason for focusing on the topic of genetics is technical. In Western Australia, where the research was conducted, genetics is mandated in our science curriculum documents and genetics is typically taught in year 10, the final year of compulsory science. Thus, it was anticipated that the findings would be relevant and of interest to many science teachers. Third, our discussions with science teachers have indicated that they are concerned about how to deal with the unavoidable issues that arise when teaching students about diagnosis, prevention and treatment of genetic diseases.

The findings presented in this paper form part of a larger research study conducted by the authors. The research questions addressed in this paper are:

1. How does an intervention based on argumentation impact on the structure of Year 10 students' argumentation and type of informal reasoning about a genetics socio-scientific issue?
2. How does an intervention based on argumentation impact on Year 10 students' understanding of genetics?

In the conclusion we discuss some of the methodological issues arising from this study and propose suggestions for those involved in similar classroom based research.

Methods

The research method was a multiple case study (Stake, 2006) with mixed methods of data collection (Cresswell & Plano Clark, 2007). The study utilized both qualitative and quantitative data sources. The research was conducted as three case studies in three schools with four science teachers and their year 9 or 10 students (13-15 years old) who were studying genetics. Each of the four teachers participated in a professional learning session on argumentation, decision-making and socioscientific issues in genetics. These teachers then explicitly modeled and taught argumentation skills to their students over several lessons. The teachers introduced students to the parts of an argument including claims, data, warrants, backings, qualifiers and rebuttals. Working individually, the students then used writing frames about two socioscientific issues. The writing frames contained prompt questions designed to scaffold the structure of an argument. Students also participated in whole class discussions and small group work to develop and justify decisions about socioscientific issues related to genetically modified foods and cystic fibrosis (Dawson and Venville, 2008).

Sample

Details of the school type, teachers' backgrounds and experience, professional learning, classroom intervention, genetics topics and data sources for each of the three cases are summarised in Table 1.

Data sources and analysis

A quasi-experimental design with a pre- and posttest was used to examine the effect of teaching argumentation on students' argumentation skills, informal reasoning type and understanding of genetics. The students in the experimental group were taught genetics and argumentation by teachers who participated in the professional learning while the comparison group were taught the same genetics topic by teachers from the same schools who had not participated in the professional learning and did not teach argumentation.

Argumentation and informal reasoning skills were measured before and after studying genetics by analysing students' written responses to a socioscientific issue on designer babies (research question 1). Students were presented with a scenario where it was possible to create a disease free designer baby for a cost of \$10000 (see Appendix A). Students were asked whether the procedure should be allowed and were offered choices of 'yes', 'no' or 'I don't know.' They were then asked to write as many reasons as possible to justify their decision.

The students' written responses were analysed using two methods. To determine the complexity of the argument used by each student, a classification scheme based on Toulmin's argumentation pattern (TAP) was used (Dawson & Venville, 2009). Students' written arguments were assigned a level or score from 0 to 4 depending on the presence of claims (decision only), data (evidence to support claim), warrants (relating data to claim), backings (assumptions to support data/warrant) and qualifiers (conditions under which claims or data are true). Level 1 arguments consisted of a claim only; level 2 arguments comprised a claim, data and/or warrant; level 3 arguments included a claim, data, warrant, backing or qualifier; and Level 4 arguments included a claim, data, warrant, backing and qualifier. No response was scored as a 0.

In order to determine the type of informal reasoning used by the students, a method previously used by Sadler & Zeidler (2005a) and Dawson and Venville (2009) was used. Students' responses were classified as rational (logical, using correct scientific language, evaluating risk), emotive (care, empathy, concern for others) or intuitive (gut response, personal). The responses were scored as rational (a score of 3), emotive (a score of 2) or intuitive (a score of 1). All student responses for argumentation and informal reasoning were coded blind by two researchers. Pre- and posttest scores for all students were entered into an SPSS database and analysed statistically. Differences in pre- and posttest scores for argumentation and informal reasoning were analysed statistically using a Wilcoxon Signed Rank Test while differences between the experimental and the comparison groups were analysed using a Mann-Whitney U Test.

The conceptual understanding part of the survey was made up of 18 multiple choice items and three short answer items that probed students' understanding of genetics concepts (research question 2). The maximum score for the test was 52. The short answer items probed students' understanding of the relationships between genetics concepts such as DNA, genes and chromosomes as well as their ability to understand the principles of inheritance. Differences between the pre and post scores for the experimental and comparison groups were analysed using a repeated measures ANOVA.

Table 1 Brief description of case studies

	CASE STUDY 1	CASE STUDY 2	CASE STUDY 3
School Description	•Co-educational catholic independent	•Co-educational catholic independent	•Co-educational wholly government funded
Experimental group Teacher/s	•Male biology teacher (19 years experience)	•Female biology teacher (7 years experience)	•Female biology teacher (7 years experience) •Female, non-biology major teacher (15 years experience)
Comparison group teachers	<ul style="list-style-type: none"> • Male biology teacher (7 years experience) • Male biology teacher (5 years experience) 	<ul style="list-style-type: none"> • Male biology teacher (8 years experience) 	Female biology teacher (1 year experience)
Intervention group	Year 10 n=46	Year 9 n= 23	Year 10 n= 58
Comparison group	Year 10 n=46	Year 9 n=50	Year 10 n=21
Professional learning	Brief (90 minute) professional learning on socioscientific issues, argumentation, decision-making	Two days on genetic diseases, socioscientific issues, argumentation, decision-making	Two days on genetic diseases, socioscientific issues, argumentation, decision-making
Classroom Intervention	•2 x 50 minute lessons including small group and whole class argumentation •Writing frames	•3 x 50 minute lessons including small group and whole class argumentation •Writing frames	•2 x 50 minute lessons including small group and whole class argumentation •Writing frames
Genetics topic	40 lessons, cells, inheritance, genetics, genetic diseases	24 lessons, cells, reproduction, genetic variation, inheritance, ethical issues	28 lessons, reproduction, inheritance, genetic variation, natural selection, ethical issues
Data sources	<ul style="list-style-type: none"> •Pre/post survey •Classroom observation •Post student interviews •Post teacher interviews •Writing frames •Teacher's plans 	<ul style="list-style-type: none"> •Pre/post survey •Classroom observation •Post student interviews •Post teacher interviews •Writing frames •Teacher's plans 	<ul style="list-style-type: none"> •Pre/post survey Writing frames •Teachers' plans

Results

Argumentation Quality

In each of the three cases, the quality of argumentation for the experimental group and the comparison group were compared pre and post-instruction. Overall, it was found that the incidence of Level 1 (claim only) and Level 2 (claim, data and/or warrants) arguments were the most common in both experimental and comparison groups before instruction. The experimental groups, however, showed greater increases in Level 3 and Level 4 arguments compared with the comparison groups who only showed a very small or no increase in Level 3 and Level 4 argument.

A Wilcoxon Signed Rank Test showed that the improvement in argumentation in all three experimental groups from pre-instruction to post instruction was significant. (case study 1, $p < .001$, case study 2, $p < .05$, case study 3 ($p < .05$). There was no significant improvement in the comparison groups in case study 1 and 3 but there was a slight improvement in case study 2 ($p < .05$). A Mann-Whitney U Test showed post unit scores for the experimental groups in case study 1 and 3 were significantly better than for the comparison groups (case study 1, $p < .01$, case study 3, $p < .01$). A result was not possible for case study 2 because the experimental and comparison samples were not equivalent.

The following example from a student in the experimental group in case study 2 illustrates the improvement in argumentation from pre to post instruction.

Student 74 Pre – I don't know. I think it should be allowed to take out genetic diseases but not to make your baby different looking (Level 1, claim only)

Student 74 Post – I don't know (claim) because in some ways it is right in being able to take out genes for genetic disorders because it will save the parents and child a lot of pain (data). I think you shouldn't be able to change things such as sex, intelligence, height and hair colour (qualifier) because it shouldn't be the parent's decision and is interfering with nature (data). If everyone had designer babies then a lot of people's hair colour, height etc would be the same and not unique to a person and special (backing). (Level 4)

Informal Reasoning Type

In each of the three cases, patterns of informal reasoning for the experimental groups and the comparison groups were compared pre and post-instruction. It was found that the incidence of rational informal reasoning increased post-instruction in all three experimental groups. A Wilcoxon Signed Rank Test showed the improvement in the experimental groups from pre-instruction to post instruction was significant in all three cases (case study 1, $p < .01$, case study 2, $p < .05$, and case study 3, $p < .05$). There was no significant improvement in informal reasoning in the three comparison groups.

A Mann-Whitney U Test showed post unit scores for the experimental groups in case study 1 and 3 were significantly better than for the comparison groups (case study 1, $p < .05$, case study 3, $p < .001$). A result was not possible for case study 2 because the experimental and comparison samples were not equivalent.

The following two examples from the experimental group in case study 2 illustrate the change in informal reasoning from pre to post instruction.

Student 68 Pre – No. because it is not right to play God. (intuitive)

Student 68 Post – No. There may be serious errors if the baby doesn't develop properly and ends up with a disorder and it is not right to play God and you shouldn't do this because it has not been tested and they aren't 100% sure it will be disease free. (rational/intuitive)

Student 66 Pre – No. I think the baby should be naturally born because the average parent would want their son/ daughter to look like them. (emotive)

Student 66 Post – Yes. This discovery (sic) could be the cure for cancer and diseases. Only the rich would be able to afford this designer babies project (sic). Scientists need to do a lot of research to analyse (sic) the risks involved. (rational)

Conceptual Understanding

A repeated measures ANOVA indicated that the students' mean genetics scores in all three experimental groups and comparison groups from case study 1 and 2 did improve significantly over time, ($p < .001$), which would be expected because the students were studying genetics during the period between the pre-unit and post-unit surveys. It is of concern that the comparison group in case study 3 did not improve despite the students studying the same genetics topic as the experimental group. The repeated measures ANOVA indicated that the gain in the experimental groups' mean scores was significantly more than the gain in the comparison groups' mean scores for case study 1 ($p < .05$) and case study 3 ($p < .001$). There was no significant difference between the experimental and

comparison group in case study 2. It is worth noting, however, that the students in the experimental group in case study 2 were very social and talkative. The mean scores and standard deviation before and after studying genetics for the experimental and comparison groups in each of the three cases are summarized in Table 2 below.

Table 2 Descriptive statistics for the pre-instruction and post instruction genetics knowledge scores for the comparison and experimental groups.

Group treatment	Time	Case study 1		Case study 2		Case study 3	
		Mean	SD	Mean	SD	Mean	SD
		(of 52)					
Comparison	Pre-instruction	10.70	4.34	8.55	3.56	7.81	3.52
	Post-instruction	17.74	8.98	17.92	8.82	8.81	5.61
Experimental	Pre-instruction	12.52	5.76	7.15	2.60	7.91	3.69
	Post-instruction	22.50	7.99	15.60	7.17	16.48	6.22

Conclusions and Implications

The results of this research demonstrate that, in all three case studies, an intervention that included teacher professional development on argumentation, socioscientific issues and decision-making followed by explicit instruction on argumentation in students' genetics classes resulted in students significantly improving their quality of argumentation and using a rational type of informal reasoning about a genetics socioscientific issue. These findings are significant as they indicate that a targeted professional development session and a brief classroom intervention can improve students' argumentation skills and change their informal reasoning type from intuitive and emotive to rational. In two of the three cases the students who were taught argumentation skills improved their genetics knowledge significantly more than the comparison group. This finding indicates that development of argumentation skills may promote conceptual understanding.

There are several methodological issues and questions related to this research study which should be considered. These issues are:

1. Different teachers taught the experimental and comparison groups in each case study.
2. Students were not randomly assigned to groups.
3. The intervention was similar but different across cases.
4. The intervention was modest.
- 5 Students' argumentation skills and informal reasoning were determined through written responses.
- 6 Is change in argumentation sustained and/or transferable to different contexts?

The methodological issues arising out of this study are largely due to the nature of school structures. As researchers working in schools we are ethically obliged to cause minimal disruption to both teachers and students.

In Western Australia, where the study was conducted, students attend high school in years 8 to 12 (about 12-17 years of age). High school science teachers usually specialize in biology, chemistry or physics in their university studies and will teach in their specialty area in years 11 and 12. In years 8 to 10 science teachers typically teach all science topics (biology, chemistry, physics and earth science) and remain with the same students over a whole school year. The four teachers who participated in the professional learning and taught argumentation skills to their students were biology specialists who had volunteered to participate after being approached by the researchers. In this study, we made every effort to ensure that the experimental and comparison groups were comparable. In each case, both groups attended the same school, studied the same genetics topic for the same length of time in the same year, and were taught by biology specialists.

However, it is still possible that differences in the experimental and comparison groups in regard to genetics understanding are due, in part, to the expertise of the teachers. We endeavoured to reduce the effect of this variable by selecting comparison group teachers who were biology specialists. We could not control for years of experience. To address this issue, in 2009, we identified two schools where year 10 students changed teachers each term so that they were all taught genetics by the same biology specialist. We have recently completed a further three case studies with three teachers from these schools using a similar quasi-experimental design where both the experimental group and the comparison groups were taught genetics by the same teacher. In each case, the teacher taught a genetics topic to the comparison group and then participated in a brief professional development session on argumentation, socioscientific issues and decision-making. The teachers then taught the same genetics topic, with the addition of the argumentation lessons, to the experimental group. At the time of writing, data analysis is underway.

An alternative explanation for improved genetics understanding in the experimental groups of case study 1 and 3 is that the students in this group were more academically able than students in the comparison groups. The structure of schools is such that it is not possible to randomly assign students and teachers to experimental or comparison groups. While the mean genetics understanding scores for each group before studying genetics indicates that there were no significant differences, we can not exclude this possibility.

In each of the three case studies reported here, the four teachers participated in similar professional learning experiences of varying lengths and then designed and implemented their argumentation lessons using the writing frames and lesson plans that were supplied by the researchers. Each of the teachers differed in the approach taken. It is not possible to determine how this variation affected students' argumentation skills.

The argumentation intervention was brief and it is possible that a more sustained intervention may have produced more conclusive results. In the three case studies, the argumentation lessons with the experimental group were conducted over 2-3 lessons during a genetics topic of 24-40 lessons. During that time the comparison group continued to study their genetics content. At the end of the topic, both groups completed formal school examinations on genetics content. We did not want to risk disadvantaging the experimental group by prolonging the intervention because they needed to complete the same amount of genetics content.

In this study, students' argumentation quality and informal reasoning type were determined through an individual written response to a genetics socioscientific issue about a designer baby. It is not known whether students' written responses are indicative of their ability to construct a verbal argument either within their science classes or in other contexts.

Finally, a desired outcome of developing students' argumentation skills is that students will use these skills when evaluating and justifying decisions about socioscientific issues they encounter later in life. Thus, any improvement in argumentation skills or change in informal reasoning type would need to be both sustained and transferable to new contexts. In late 2009, we will be re-testing students nine months after an argumentation intervention to determine students' argumentation skills and reasoning type using a different genetics socioscientific issue and an environmental socioscientific issue.

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Appendix A

A Sydney IVF clinic has recently been offering to produce 'designer babies' for parents. For just \$10,000 the clinic will check and, if necessary, change the parent's genes in order to produce the baby of their choice. Once selected, the baby develops normally inside the mother. The choice at the moment is limited to sex, intelligence, height and hair colour but a spokesperson said that several other features would soon be available. All 'designer babies' are guaranteed free from identifiable genetic diseases.

Do you think this use of gene technology should be allowed?

Write as many reasons as you can to support your answer.