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The use of Cartography of Controversy within socioscientific issues-based education: students' mapping of the badger-cattle controversy in England

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ABSTRACT

This qualitative study examines the pedagogical potential that a Cartography of Controversy (CoC) approach has in enabling secondary school students to unravel the complexity of socioscientific issues and to communicate about them. The aim was to examine the types of knowledge and the ways in which students approached uncertainty when asked to explore the badger-cattle controversy in England using the CoC approach. A learning sequence focusing on mapping controversies was designed and implemented across three lessons. Data collected from the students' cartographies and the audio-recordings of their group discussions during the mapping tasks showed that students were able to use scientific, economic, cultural, social, moral and political types of knowledge in their exploration of the controversy. Identifying tensions between different types of knowledge and becoming aware of their own uncertainties about the issue through posing and recording questions allowed students to identify where uncertainty existed within the SSI explored. The CoC approach allowed affordances for understanding the SSI depending on students' framing of the task (familiarisation, exploration, consolidation) and on the cartography's function as an observation, visualisation, and reflection tool at different stages of the learning sequence. Implications for further research and practice for developing students' socioscientific reasoning are discussed.

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Introduction

In contemporary societies, disputes often arise from socioscientific issues (SSI) which are rooted in science, technology and politics. Science education for active civic participation could utilise SSI to help young people realise the links between science and society. SSI are issues arising from scientific and technological research with implications and

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applications to society and everyday life, with social, moral, economic and political dimensions to them (Ratcliffe & Grace, 2003; Zeidler, 2014). SSI are often based on 'science-in-the-making' (Latour, 1987), which is characterised by a higher level of uncertainty surrounding the scientific knowledge linked to them, and a high level of controversy about how such scientific knowledge is to be used best within society.

A key feature of SSI-based education is that it allows students to learn about the content and practices of science as well as learn about the controversy itself (Sadler et al., 2007; Zeidler, 2014). Research into SSI-based education has supported ways of structuring pedagogical approaches focusing on democratic participation and citizenship education within the wider framework of science education (Hand & Levinson, 2012; Ratcliffe & Grace, 2003). However, less is known about the processes students use when exploring SSI, such as to what extent they are able to identify and navigate the different levels of the SSI's controversy, and where the uncertainty lies within the types of knowledge and viewpoints they identify (Elam, Solli, & Mäkitalo, 2019; Levinson, 2010; Solli et al., 2017; Zeidler, 2014). Additionally, tensions such as students' difficulty to reconcile uncertainty with their views on SSI have been recently identified (Lee, Lee & Zeidler, 2020). In this article, we examine how a Cartography of Controversies (CoC) approach can be used to engage students in communicating about a localised SSI – the transmission of *Microbacterium bovis*, known as bovine tuberculosis, from badgers (*Meles meles*) to cattle in England. The research questions are:

RQ1: What knowledge do students draw on when communicating about the badger-cattle controversy within a CoC approach?

RQ2: How is complexity represented in students' communication about the badger-cattle controversy within a CoC approach?

Secondary school students' engagement with, and communication about SSI

Studies indicate that when discussing SSI students often go beyond scientific knowledge to take into account social and ethical dimensions (e.g. Chang Rundgren & Rundgren, 2010; Lee et al., 2019; Nielsen, 2012), as well as their personal experiences (Albe, 2008; Evagorou & Osborne, 2013). Rundgren et al. (2016) report that in their in-depth qualitative exploration of seven secondary school students' decision-making on an environmental issue, students' decisions on the issue were dependent on their background knowledge, values and experiences. Nielsen (2012) found that secondary school students discussing gene therapy were able to use scientific information to frame an issue or to invite other students to argue for or against it allowing for dialogic argumentation to be advanced and positions to be further explored. Conversely, Walker and Zeidler (2007) found that when students engaged in socioscientific argumentation about genetically modified foods, they employed hypothetical and fallacious reasoning based on factual content, due to the students' lack of further knowledge and deep understanding of the issue explored.

Such evidence suggests that methodological and pedagogical approaches need to consider how students can deepen their understanding of SSI in a holistic manner, and to

make explicit the interconnections between different epistemic and non-epistemic characteristics of SSI, such as scientific evidence, moral and ethical values, political and economic dimensions (Hand & Levinson, 2012), in order to enable students to engage in deliberation and communication about SSI. Albe (2008) notes that the role controversy plays in the advancement of science needs to be better understood by students, as this helps to bring uncertainty to the foreground and makes it a central issue of consideration for students. Consequently, students need to be able to identify and analyse areas of contention, understand reasons for disagreement and consider alternatives; that is, students need to be able to unravel the complexity of controversy within a SSI, and approaches that facilitate such discussion and deliberation of controversial issues are therefore required.

Unravelling the complexity of SSI

An approach to untangle the multiple levels of complexity within SSI is using cartographies of controversies, a strategy which focuses on the investigation and analysis of public disputes around techno-scientific issues (Venturini, 2012) based on Latour's (2005) actor-network theory (ANT). ANT postulates that science progress and technological innovation are not based on individual action alone, but also on the interaction and relationships between various human and non-human, material and non-material actants[1] as part of a dynamic social network. Controversies are created when actants within a network focus on matters of concern and raise questions that create disagreement (Venturini, 2010).

Knowledge controversies can be seen as 'generative events' (Whatmore, 2009) where multiple perspectives, values and knowledge are examined and interrogated making the complexity of a controversy more 'legible' (Venturini, 2012, p. 797). CoC can achieve this by facilitating the representation (Venturini, 2010) or *visualisation* of events, which in turn can bring controversy into the public sphere, where it can be explored, analysed and understood (Schoffelen et al., 2015). The mapping of a controversy's various components and its visualisation also provides an opportunity for *observation* of multiple perspectives and connections, which can consequently provide opportunities to identify more readily tensions between perspectives, raise questions and initiate further exploration of events.

The use of ANT allows for a more holistic examination of associations between science and society where taken-for-granted ideas can be questioned and debated, the relations between concepts examined (Venturini, Munk, & Jacomy, 2019) and where the sociopolitical dimensions of an issue are considered as equally important as its techno-scientific dimensions (Elam et al., 2019). These reasons provide a rationale for incorporating an educational version of ANT (Venturini, 2010) to pedagogical approaches within SSI-based education, such as the one reported in this study.

Venturini (2010) discusses how mapping controversies can become an educational version of ANT when individuals are not pre-occupied with its methodological and theoretical assumptions, and instead focus on considering as many perspectives and voices as possible and listening to actors' voices without being influenced by their own preconceptions of the controversy examined. That is the approach we use in this study. At the same time, we acknowledge that the mapping of controversies is not a

simple task due to the multifaceted and open-ended nature of controversial issues, and that criticisms related to its theoretical grounding in ANT exist, which need to be considered. For instance, feminist critiques of ANT (Oudshoorn & Pinch, 2008) have focused on the lack of acknowledgement of power relations between diverse actants, while Whittle and Spicer (2008) address ANT's lack of political critique in transforming power relations in organisations. Nonetheless, Latour (2005) has emphasised ANT's descriptive possibilities. It is the sensibility to the relational, the refusal to essentialise the subject-object relationship, which is at the heart of our rationale for deploying ANT techniques in this study.

France et al. (2017) and Elam et al. (2019) support the view that CoC could be used in educational settings to help students gain an appreciation of controversies and their complexity. Pedagogical approaches based on ANT and CoC have been used to enable students to become actants and not just spectators of a controversy (Agbessi & Mathieu, 2015), and have used the CoC as a digital mapping method (Venturini, 2012). Solli and colleagues (Elam et al., 2019; Mäkitalo et al., 2019; Solli et al., 2017) have used CoC as a form of digital inquiry to engage secondary school students in socioscientific reasoning. Solli et al. (2017) explored how Grade 11 students used digital mapping tools when learning about hydraulic fracturing (fracking). Students were asked to use digital maps they constructed as prompts to explain fracking to others (Grade 12 students) and debate the issue with them, although the ways in which issues of complexity of the controversy were raised during the construction of the maps are less clear. Despite its educational potential, to the best of our knowledge, no studies have been identified to date within science education that use the CoC approach as part of everyday classroom settings to explore how students deal with, unravel and communicate the complexity of the controversy of a SSI *whilst* constructing their cartographies, which is the aim of our study.

Study context

The current study took place within the CASSIS (Communicating About Socio-Scientific Issues) project exploring how secondary school students communicate about controversies surrounding agricultural 'pest' animals in the UK, France and New Zealand; we focus here on the controversial role of badgers in the UK countryside. The badger is considered a pest animal by some in the agri-industry due to its agency in the transmission of bovine tuberculosis (bTB) to cattle and has resulted in one of the most contentious policies based on (or lack of) scientific evidence, in the UK (Godfray et al., 2013). Since the UK government's proposal to cull the badger population in 2013, various protests were organised, supported by agencies such as the Royal Society of Prevention of Cruelty to Animals (RSPCA) and celebrities (BBC News, 2018). Badger culling is a SSI because various standpoints can be adopted across the socio-scientific landscape, incorporating a range of dimensions: scientific (e.g. the uncertainty of the process of transmission); economic (e.g. the financial impact on farming and dairy industries); political (e.g. EU regulations that affect policy making); ethical (e.g. whether it is moral to kill one animal over another, whether human lives should be valued over other animals); and sociocultural (e.g. the badger's place in British folklore and literature).

On one level, the controversy centres on whether the badger is the key biological vector of the disease, or whether transmission also occurs from other animals to cattle,

and from cattle to cattle (Krebs et al., 1998). The exact manner by which transmission takes place is yet to be determined with certainty (Godfray et al., 2013). Whether current farming practices and farmers should be made more accountable for the issue is also debatable; for instance, farm husbandry and biosecurity practices could be used to reduce bTB transmission risks (Ward et al., 2010). Further, there is inconclusive evidence for the effectiveness of the badger cull in the affected areas (Brooks-Pollock et al., 2014).

The politico-economic argument in support of a badger cull is based on the importance of protecting the dairy and meat industries, which are major stakeholders in the country's economy. EU legislation prohibits the export of meat and/or dairy products affected by bTB, although the within-country distribution of products is permitted. This legislation addresses public health concerns (protecting humans from contracting TB), which raises another aspect to the controversy since with the introduction of pasteurisation of milk and regular tuberculin testing in cattle the instances of TB in humans as a result of consuming infected products have been scarce (Krebs et al., 1998; Godfray et al., 2013); however, there is still a risk that needs to be addressed.

The environmentalist argument opposing the badger cull centres on the importance of biodiversity and is combined with moral arguments in support of animal rights. Reports that the badger cull has not been conducted in a 'humane' manner was the issue of much discussion in the media after the first round of culling in 2014 (BBC News, 2014). Finally, there is a strong cultural dimension to this controversy based on the badgers' role within British folklore, especially in children's literature such as *The Wind in the Willows* (Grahame, 1966), which can promote a romanticised image of badgers, and which might affect the way in which the public approach the controversy.

Methodology

This small-scale study employs an exploratory, qualitative study design to explore how complexity is represented by students and the types of knowledge they employ as they analyse the badger-cattle controversy using the CoC approach. The student sample was 13 Biology students in Year 12 (16–17-year olds, 12 females/1 male) of a rural state school in the south of England. Students were not familiar with the CoC approach prior to engaging in this study's activities. Students worked in the same groups during three lessons, and the data collected during these lessons are shown in Table 1. Two groups produced a complete data set and were chosen as the two groups (eight female students) for data analysis. A lesson sequence based on the CoC approach was designed and implemented across three lessons (Table 1).

The instructions given to students at the beginning of Lesson 1 about how to construct their cartographies were kept as simple as possible. They were asked to draw their cartographies by hand on a large sheet of paper using coloured pens, and to represent 'actants' by including them in rectangular boxes, and descriptors of relations between the actants by using arrows and words. Students were free to add as many actants and connections as they thought relevant, and they had to decide themselves within their groups, who would take responsibility for constructing the map according to the group's instructions and discussion. In all groups, it was decided by students that one person would take responsibility for constructing the map by adding on their paper sheet what was being discussed

Table 1. A summary of the CoC lesson sequence implemented and the data collected.

Lessons 1 and 2 (2 × 1-hour): Mapping the controversy	1. Students given a summary of the issue with two possible solutions. 2. Students work in groups of 3/4 to: • construct a controversy map to illustrate as many actants in the controversy as possible; • write on their maps any questions that arise during the discussion/mapping activity; • use laptops to research topic/questions; • take a position individually and justify it after the map construction. 3. Discussion of guidelines for using the blog critically and constructively Data collected: maps, audio recordings of group discussions, individual positions
Online communication (2 weeks)	Guiding question: 'What should be done about the controversy?' All students to contribute at least twice with their own views and response to others' contributions to answer the guiding question Data collected: blog entries
Lesson 3 (1-h): Re-mapping the controversy	Students work in the same groups of 3/4 with the same instructions as in Step 2 of Lessons 1 and 2 Data collected: maps, audio recordings of group discussions, individual positions

by the group. Students were also asked to write on their maps any questions that arose during their discussions.

A summary sheet of the controversy was provided including brief information about bTB, badgers and two possible ways of dealing with the transmission of bTB to cattle (culling badgers and vaccination). In providing this summary and instructions, we wished to make the mapping task as open as possible, by allowing students to illustrate through their choices of what they added on their cartography; the actants and connections *they* considered important at that point in time. Further, providing information on two possible ways of dealing with the issue indicated to students that there was not one correct answer. The open-ended task also aimed to encourage discussion of various positions instead of students selectively drawing on evidence given to them to argue for a predetermined position (Evagorou et al., 2012; Rundgren et al., 2016). The remainder of Lesson 1, and Lesson 2 were focused on the cartography construction, with the researcher and teacher present, who both adopted a supportive, non-participant role, mainly encouraging the students to pursue ideas and questions they had about the issue. Contrary to Solli et al.'s (2017) study, the aim of the mapping task was not to have students debate the visualised controversy, but to enable students to construct collaboratively their representation of the controversy. The purpose of the blog was to allow students to communicate their ideas clarifying their own positions and arguing for solutions, away from constrains of typical classroom settings, for two weeks. During Lesson 3 students were asked to re-map the controversy, following the same instructions and procedures (e.g. one student assigned the writing role) as in Lesson 1.

Data analysis

Content analysis of the maps was employed to determine the number and range of actants and connections students identified and included on their maps. One member of the research team conducted this content analysis initially, and other members then checked for accuracy independently. We take the view that the actants students choose

to include on their maps constitutes an indicator of what they consider to be relevant and important for the controversy at that point in time since the cartography is a representation of a particular social network, which is dynamic and fluid. The number of connections for each actant was included as an indication of students' understanding of the complexity of the controversy, and of the 'representativeness' (Venturini, 2012) or the prevalence it has within the controversy.

To further explore the types of knowledge used, four of the authors constructed independently a narrative interpretation for each map. These narratives were shared and compared, and an iterative process was followed until a shared understanding and agreement between the authors was achieved about how complexity was represented and framed by the groups on each map. A further step of interrogating the data for triangulation purposes was contrasting the narrative descriptions of the maps with the transcript of the discussion during the map construction. Thematic analysis of the textual data (group discussion transcripts and blog entries) was conducted separately from the narrative reconstructions using the constant comparative method (Glaser & Strauss, 1967). The themes identified were then categorised into main themes and subthemes. The blog entries by students from each group were identified and then compared with the themes emerging from the map analyses.

Findings

The presentation of findings shows the types of knowledge and ways students represented complexity at each of the three lesson sequence stages (Table 1). The results of the maps' content analysis from groups A and B are provided in Table 2. A reconstruction of the maps created by the two groups is provided as supplementary material.

Group A findings

Unravelling the controversy – Map 1: The content analysis of Group A's Map 1 indicates that this group drew on scientific, economic, political, and ethical types of knowledge. 'Culling' was a central actant with the most connections (specialist shooters, National Farmers Union, environmental groups, reduces biodiversity, badgers, farmers, cows). 'Cows' was also a central actant with six connections (*M. bovis*, vets, culling, farmers, abattoirs, urine and droppings). Two key areas of uncertainty were identified on Group A's Map 1 (Table 3). Students discussed the uncertainty around infection and treatment, as also evidenced by their questions (Figure 1) and around infection and vaccination (as a possible solution); in both cases, they drew on political (e.g. 'what happens when the UK leaves the EU?', 'why is cattle vaccination illegal under EU legislation?') and scientific (e.g. 'pasteurisation kills M.Bovis', 'most people immune to TB') types of knowledge. Map 1 includes multiple levels of the controversy as social groups with opposing views on the badger cull were represented (environmentalists, National Farmers Union, farmers, people, RSPCA). The analysis of the group's discussion during the construction of Map 1 and the questions students raised on their maps (Figure 1) reveals that students framed the controversy based on the 'necessity of badger culling' and its cost-effectiveness (Table 3).

Table 2: Summary of actants identified by each group during the two mapping activities (lighter-shaded cells indicate actants in Map 2 also present in Map 1; darker-shaded cells indicate actants in Map 2 not present in Map 1; actants in bold indicate 4 or more connections to other actants)

Group A		Group B	
Map 1	Map 2	Map 1	Map 2
Badgers (3)	**Badgers (4)**	**Badgers (5)**	**Badgers (5)**
Cows (6)	**Cows (4)**	**Cows (4)**	Cows (3)
Specialist shouters (1)	Specialist shooters (1)	Legal shooters (2)	Legal Shooters (3)
Farmers (3)	Farmers (3)	**Farmers (5)**	**Farmers (6)**
Environmental groups (2)	Environmentalists (2)	Environmentalists (1)/ Environment (2)	Environmentalists (3)
			Badger supporters (1)
TB (2)	**TB (4)**	**TB (3)**	**TB (5)**
Economy (1)	Economy (1)	**Economy (3)**	**Economy (6)**
Abattoirs (2)			Production (2)
	Jobs (2)		
Loss of profit (2)			Customers (3)
Culling (7)			Guns (culling) (3)
Biodiversity (3)	Species diversity (1)		Other species (1)
People (3)	**People (5)**	Locals (2)	General population (3)
	General public (1)		**Residents (5)**
***M.bovis* (6)**			
			Police (2)
			Crime (2)
Urine and droppings (2)			
	EU (1)	**EU/Government (4)**	EU (3)
	Butchers (2)		Butchers (2)
	Breeders (1)		
National Farmers Union (1)		National Farmers Union (2)	National Farmers Union (3)
	Vaccination (4)		**Vaccinations (4)**
Doctors (2)	Scientists (3)		Scientists (3)
Vets (3)			
Pets (2)			
RSPCA [Royal Society for the Prevention of Cruelty to Animals] (1)			
	Developments in vaccinations and immunology (3)		
Treatment (2)	Cures to other diseases (2)		
	Research grants (2)		

Table 3: The themes identified in Group A's exploration of the badger-cattle controversy

	Map 1			Map 2	
Task	Cartography	Discussion	Blog	Cartography	Discussion
Themes	**Infection** – public health concerns – from other animals	**Infection** – public health concerns	**Infection** – public health concerns – from other animals	**Infection** – public health	
			Transmission – from/to other animals	**Transmission** – from/to other animals	
	Treatment – for animals and humans	**Treatment** cattle vaccination vs. public health concerns **Cost effectiveness for farmers** Cattle treatment vs. cattle killings **Necessity of badger culling** – for farmers – public health concerns	**Treatment** – vaccination – further research needed	**Treatment** – vaccination –further research needed	**Treatment** cattle vaccination vs. badger culling

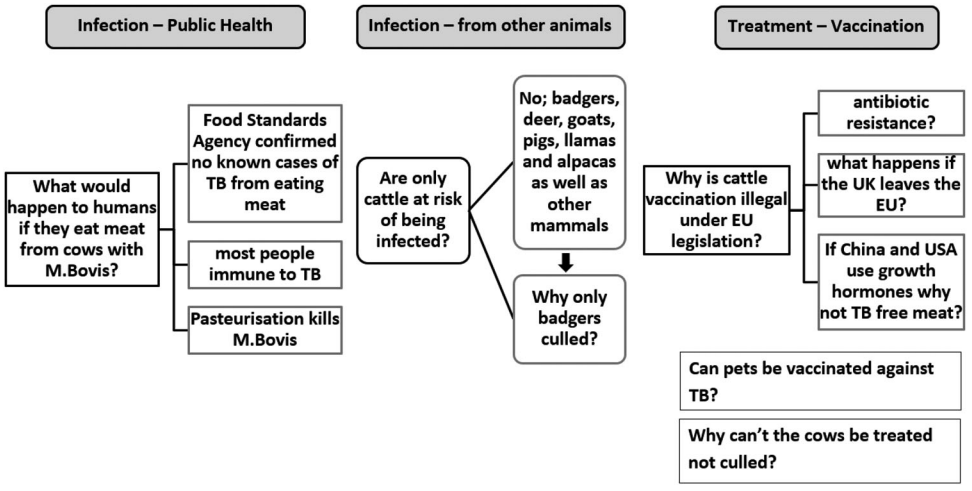

Figure 1. Areas of uncertainty for Group A students based on the questions asked during the first mapping task.

This is consistent with including economic dimensions of the controversy on Map 1 (e.g. 'loss of profit' linked to 'farmers' and 'abattoirs'). Yet, 'economy' seems to be a peripheral aspect to the controversy for students if only examining the cartography – there is only one connection to 'economy'.

Table 4 illustrates students' representation of complexity during the Map 1 construction through tensions identified when different types of knowledge (financial, social, scientific) were intersected during the construction of Map 1. S1 initiated this exchange by questioning whether bTB kills the cattle or not (line 61). Students S2 and S3 expressed certainty that 'you can't eat' infected meat (lines 62–63), which was contradicted by S4 in line 71, who raised uncertainty about whether bTB can affect humans if infected meat is consumed, illustrating students' considerations of the public health concern dimensions of the controversy, as well as their critical but constructive engagement with the task. Students considered the financial implications for farmers who would not be able to profit from their business, identifying the politico-economic level of the controversy, as well as the social implications for farmers (line 115). The mapping process acted as an observation tool, which allowed students to identify issues of concern (e.g. public health impact, social implications) and uncertainty, which led to raising the question 'Why can't the cows be treated not culled?' (Figure 1), also indicating a new possible solution, suggesting that students were expanding their perspectives as they explored the issue collaboratively. The uncertainty identified around public health concerns facilitated reflection on the issues, which led students to research online the impact on human health finding information by the Food Standards Agency that 'there are no known cases of people contracting TB from eating meat' (line 200), which made them question current prevention measures such as killing infected cattle.

At the end of Lesson 1, they pointed out that culling badgers 'is not that necessary' because 'the chances of getting it [bTB] are so low, and then we all know how to treat it, and most people are immune anyway, so we don't really get what the fuss is about' (lines 217–219).

Table 4. Transcript extract presenting Group A students' representation of complexity during the construction of Map 1.

Turn No.	Transcript	Theme
61. S1:	So, you know when … so there's the – TB kills the cattle …	Public health concerns
62. S2:	It doesn't kill them. Maybe it makes them ill, but you can't eat them	
63. S3:	You can't eat them	
64. S2:	There's no point, the farmer wasting money –	Cost effectiveness for farmers (cattle treatment vs cattle killings)
65. S1:	Why can't we find a way –	
66. S2:	– If they can't even sell it.	
67. S1:	Why can't we find a way of stopping TB being transmitted into humans?	Public health concerns
68. S4:	Well, we kind of have,	
69. S1:	So why is – So why can't we give the cow medication?	Cattle treatment
70. S2:	If the humans aren't affected, then why does the cow need to be destroyed?	Necessity of cattle killings
71. S4:	I think if you eat a TB [infected] cow then you are infected.	Public health concerns
72. S3:	Yeah, but can you not give the cow medication?	Cost effectiveness for farmers (cattle treatment vs cattle killings)
73. S2:	I think it's just too expensive, like not worth the cost of what the cow's worth.	
	[…]	
110. S1:	But I don't know, if you like give them medication, the cattle, if you did and it did work, like if it doesn't affect humans, it should be okay, shouldn't it?	Necessity of badger culling (public health concerns)
111. S2:	Yeah	
112. S1:	Like it doesn't … so could that be a question?	
113. S3:	Why can't the cows be treated and then …	Necessity of badger culling (cost effectiveness for farmers)
114. S2:	It's all economics. Say like, shouldn't it be like if your cattle has TB, shouldn't the government subsidise money for like crops and stuff [for the farmers] … ?	
115. S4:	I think some farmers literally just have cattle, and that's their livelihood	

Unravelling the controversy – Online communication: Group A used scientific knowledge and information discussed during their first cartography to take a position against the badger cull during the online communication. The justifications used for being against the badger cull were based on: public health not affected by infected cattle, other animals are also carriers of TB and could thus infect cattle, vaccination could be a possible treatment option if the UK left the EU, and finally, further research is needed to explore other treatment options. These justifications identify multiple levels of the controversy attempting to consider the value of both human and animal lives.

> I completely agree with your comment, no-one would ever think of shooting a human if they had an infectious disease so surely we should treat other species fairly too! Furthermore, other animals which can cause the spread of bTB such as deer, pigs and dogs don't seem to be taken into account. Also it will cost £1 billion to control the disease in the next 10 years if no action is taken, so it would be much better to put the effort into researching how to get rid of it immediately rather than wasting time finding badgers to kill (entry 10.2.4, S3)

Although cost-effectiveness was still part of the way in which S3 framed her argument, she was also considering the moral dimensions of the issue. She put human and other animal lives on the same level, and noted that other species should be treated 'fairly',

as humans would, a theme not identified in the discussion that took place during the first map construction by Group A.

Unravelling the controversy – Map 2: The second mapping task revealed two main themes (Table 3) with which uncertainty was represented: first, uncertainty in relation to 'infection', based on how TB infects badgers, humans and cows. Second, the uncertainty around 'treatment' was framed based on 'vaccination' and 'further research'; students now include 'vaccination' and 'scientists' explicitly on Map 2, which were only raised as questions on Map 1 (Table 2); this indicates that Group A considered these as important actants in the controversy at this point in time, acknowledging the issue as ill-structured, and as needing ongoing inquiry and investigation, which is an important dimension of socioscientific reasoning (Romine et al., 2020).

During this task, students took on a more procedural and 'taken-for-granted' approach compared to the first mapping task, with the discourse focusing on what should be represented on the map rather than exploring or deliberating on the issues surrounding various actants, and asking each other questions, as they did during the first mapping task (Figure 1). The only instance of uncertainty identified was when students discussed cattle treatment as a solution linking it to 'vaccination' and to 'EU' ('the EU don't like it cause it's like growth hormones'; line 81). This led to them identifying the only question included on their Map 2 (Does the EU support culling?).

Overall, the main source of uncertainty identified in Group A's communication is the impact on public health, which resulted in students focusing on transmission/infection and led them into a deliberation of whether the badger cull should be happening at all, rather than on its effectiveness as a preventative measure. The main level of controversy they focused on is the socio-economic level where the high financial stakes of cattle infection by bTB drive the cull, and the implications that the cull has on farmers' livelihoods. Group A shifts from a focus on the transmission process and infection of humans and animals by bTB to a focus on the treatment of groups affected. The shift of focus on treatment as a solution during the second map construction is shown by an explicit consideration of vaccination and further research, with scientists seen to be important stakeholders in the controversy; this was not present in Group A's first map construction.

Group B findings

Unravelling the controversy – Map 1: Table 5 provides the themes identified in the data collected from Group B. Their Map 1 indicates that 'bTB', 'badgers' and 'cows' are central features of the controversy. These actants were organised in a triangle on the map (badgers and cows are infected by TB; they share the same habitat, and both infect each other), and additional actants were added around them to complete the cartography in such a way that scientific, political/economic, ethical/moral and social levels of the controversy were represented. Their questions reveal uncertainty in relation to the ecosystem (Figure 2). The social dimension was illustrated by the strong representation of 'farmers', with five connections to other actants (cow, locals, economy, National Farmers Union, EU/Government).

An interesting omission was 'culling', suggesting that students focused on the culling's impact and outcomes rather than culling as an actant, which is consistent with the fact

Table 5: The themes identified in Group B's exploration of the badger-cattle controversy

	Map 1			Map 2	
Task	Cartography	Discussion	Blog	Cartography	Discussion
Themes	**Infection** – public health concerns – between animals **Impact on:** – environment – farmers	**Infection** – public health concerns – between animals **Treatment** – Public Health concerns (vaccination of cows vs. badgers) **Value of animals. population control**	**Infection** – between animals – public health **Impact on:** – farmers (economic) **Treatment** – Vaccination – Public Health **Cost effectiveness** – further research – vaccination vs. culling **Animal welfare**	**Infection** – public health concerns – between animals **Impact on:** – humans – economy **Treatment** – Vaccination	**Impact of Vaccination on:** – economy – public health **Treatment** – Vaccination

that all questions posed were focusing on the impact of the culling (Figure 2). Further, 'vaccination' was identified as a key area of uncertainty considering its impact from a political, public health and financial perspective. As with Group A, Group B only included vaccinations in their questions and not as actants on their map.

Students' discursive interactions during the map construction revealed a range of positions and types of knowledge used, with the complexity of the issue identified when tensions between different types of knowledge were taken into consideration. Table 6 presents Group B's representation of complexity as students explored the tension between the impact of cattle inflection on farmers' livelihoods, the need for (animal) population control and the value of cattle over badgers.

Group B students discussed the value of cattle over badgers with S3 taking a critical approach and questioning why cows are killed as soon as they are identified as infected by bTB (lines 76–79). Students discussed this constructively, which allowed S1 to raise the moral dimension of the controversy (line 81), before S2 responded by raising the socio-cultural dimension of the controversy (line 84). The issue of population control

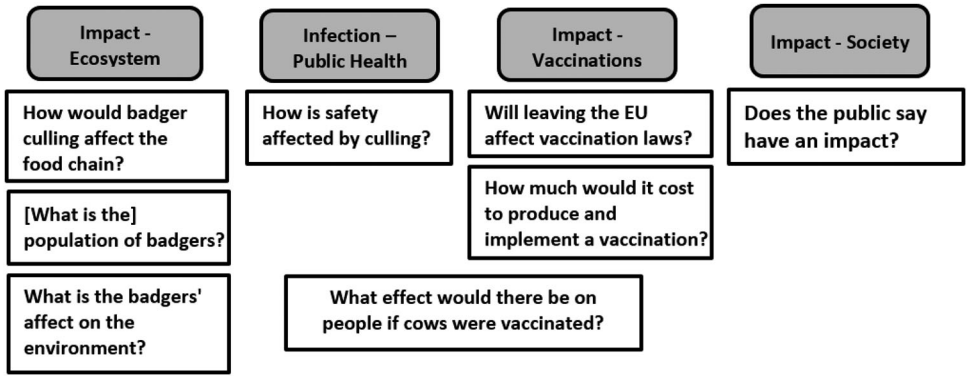

Figure 2. Areas of uncertainty for Group B students based on the questions asked during the first mapping task.

Table 6. Group B's discussion of the value of cattle over the value of badgers during Lesson 1.

Turn No.	Transcript	Theme
71. S1:	So, the farmer and economy; is the farmer then like sells it on …	Impact on farmers
72. S2:	Livelihood	
73. S1:	Livelihood, yeah, livelihood	
74. S3:	And if all his cows are killed then he doesn't have any income coming.	
75. S4:	I think that's why the cow is much more valued. I think it's more valued in the economy aspect because of its livelihood. Badgers aren't …	Value of animals vs population control
76. S3:	Yeah, why then is the cow getting killed instead of the badger?	
77. S4:	No, badgers do get killed as well, that's why.	
78. S2:	They both get killed	
79. S3:	Yeah, I know, but like straight away the cow gets killed but it's not straight away the badger gets …	
80. S2:	Because you can't control the badger	
81. S1:	Yeah, but why is one life more important than another life?	
82. S2:	Because the cow's going to die. The cow's going to die in the end anyway	
83. S1:	So, yeah, but so is the badger in the end. They're all going to die. Everything dies.[…]	
84. S2:	No, but like the cow is like going to die in a short time because like for meat or for (inaudible) whereas the badger, we don't kill them because it's part of English heritage, it's part of the rural area	

re-appeared at various points in the students' discussion during their first map construction, and was often contrasted with moral values as illustrated in Table 6, which addresses the environmentalist and ethical levels of the controversy on whether one animal should be killed over another. The uncertainty surrounding vaccinations was addressed by S2 noting 'we can't always say that that's effective' (line 98) acknowledging the challenges of vaccinating badgers (rather than cows). Uncertainty was maintained in the group's discussion until the end of Lesson 2, with students pointing out that they did not have sufficient information about the culling to make an informed decision and that 'it's just all a bit uncertain' (S3, line 488). This led them to conclude that further research into the culling and its effects was needed.

Unravelling the controversy – Online communication: Group B students' contributions to the blog are presented in Table 5. The two possible solutions of culling and vaccination were framed by students based on the financial perspective of cost-effectiveness and based on a moral perspective of valuing animal lives, as shown below:

> People use culling as an alternative to vaccination due to the ban and also, the money. The people who are specially trained or legal shooters are used and are much cheaper than vaccination. Even if we leave the EU we need to research the affects of vaccinations on humans. This is time and money. In the mean-time farmers think it makes logical sense to have the badgers culled. Also, it makes it seem as if something is being done. It isn't the correct way. Again, what makes one life more important than another? (entry 7.1.1, S3)

S3 drew on financial, political and moral knowledge in discussing the cost effectiveness of culling, which is viewed as a short-term solution as opposed to vaccinating cattle, which is both time consuming and more expensive. The cost-effectiveness perspective was identified as an area of uncertainty based on how the culling is going to affect the farmers' livelihoods and public health, and within that they considered the issue of expenditure on farmer subsidies and funding further research. The moral perspective illustrated through the themes of 'Animal welfare' (Table 5) is consistent with the issues discussed during the construction of Map 1 (Table 6), identifying tensions between

considering the position of the badger as part of the ecosystem at large, and the fairness with which humans treat badgers in particular, and animals in general.

Unravelling the controversy – Map 2: The actants of 'TB', 'badgers' and 'cows' were again presented by Group B as central features of the controversy with badgers and cows infecting each other, and 'other species' indicating it is not only badgers that are infected by, or carry TB; students thus acknowledged that badgers are not to blame entirely and demonstrated their understanding of the complexity of the controversy they were exploring, as well as the uncertainty that exists in relation to how other animals are infected. 'Economy' was also a dominant actant connected to six other actants (EU, vaccinations, legal shooters, customers, NFU, residents). This suggests a more consolidated understanding of financial factors that affect the way the problem is dealt with compared to the students' first map construction. Different social groups ('farmers', 'residents', 'general population', 'customers', 'scientists') were represented on Map 2 indicating students had considered extensively how the issue affects humans from different perspectives (e.g. public health, through connections to vaccination and TB; financial, through connections to consumerism and products used). 'Farmers' had a strong presence with six connections to other actants (cows, legal shooters, customers, NFU, guns (culling), butchers), which were more than on Map 1.

'Vaccinations' were included on Map 2 indicating Group B considered it as a main aspect of the controversy (Table 2) and connected it with 'EU', 'scientists', 'environmentalists' and the 'economy'. This suggests that students considered vaccinations as a solution more in-depth, whereas 'vaccinations' was not an actant included on Map 1. Another new actant on Map 2 was 'scientists', which also represents a new level of the controversy considered; that between possible solutions (e.g. vaccination) and the effect this might have on other scientific disciplines. Students noted that although scientists can research and develop effective 'vaccinations', their time is taken away from researching other diseases that can benefit the 'general population' (SI, line 190). This creates uncertainty during the students' discussion and a tension between the benefits of vaccination as a solution to the badger cull and the implications the research and development process of vaccinations have on public health is observed.

Students' use of scientific knowledge on biodiversity and population control during the first map construction led them to focus on other levels of the controversy, such as the economic level by discussing the impact of the badger cull on the economy and farmers, rather than the moral/environmental level, as they seemed to agree with the proposition that it is easier to control cattle. Similarly, during the second map construction, students' use of scientific knowledge in discussing how bTB might cross the human species barrier (lines 287–306), allowed them to reflect on this issue as they reviewed the visualised controversy on their cartography and eventually reached consensus on that transmission to humans is 'unlikely'. For instance, in response to S1's question on whether 'an increase in infected meat [would] cause TB to be present again in humans' (S1, line 305), S3 concluded:

> if you're saying someone gets TB because they eat infected meat, then that means the quality control of the meat and what the farmers [are] doing – then that means there are multiple, because why, because obviously it goes cow to human. If you think about all the things in between, you're saying that they all failed and all mucked up and are all wrong (S3, line 309)

This allowed Group B to represent complexity to a higher degree on their cartography, as they focused on issues around quality control and legislation. The only instance of uncertainty raised during Group B's second mapping task was the discussion of public health concerns and whether transmission to humans was likely. Similar to Group A, the students in Group B adopted a procedural approach to completing the second mapping task compared to the first. That is, the members of the group would suggest actants and the student writing would add the suggestions to the map; they then proceeded with labelling the connections between the actants, without any exploration of issues or concepts involved, and only one question was raised that was written on their cartography ('Can the disease cross to our species barrier?) which they resolved agreeing that it does, and thus adding the answer 'Yes' under their question.

Discussion

The aim of this study was to examine the knowledge students drew on when communicating about the badger-cattle controversy, and the ways in which students were able to represent the complexity of the issue when utilising the CoC approach.

Types of knowledge used to discuss the badger-cattle controversy and representation of complexity

To answer RQ1 we examined the range and types of actants students used on their maps during their group discussions and within the students' blog contributions. Both groups were found to use a range of types of knowledge during their map constructions and discussions. These types of knowledge included scientific, economic, cultural, social, moral and political knowledge. This finding is consistent with previous studies that discuss the range of types of knowledge students utilise within SSI-based education (Albe, 2008; Chang Rundgren & Rundgren, 2010; Lee et al., 2019) and further points to the importance of SSI-based education for supporting students in learning to manage such complex issues. We also found instances (e.g. Group B Findings section) where students' use of scientific knowledge created consensus and resolved uncertainty that allowed students to explore further other levels of the controversy. This finding further supports the discussion on the role and significance of scientific knowledge within SSI-based education as discussed by studies such as Nielsen (2012) and Walker and Zeidler (2007) amongst others, and points out that further research is needed for understanding how scientific knowledge, as well as reliable, evidence-based knowledge in other domains such as politics, and the economy can facilitate or impede students' engagement with complex SSI.

To answer RQ2, we found that students in the two groups were able to represent complexity by acknowledging tensions between the scientific, economic, cultural, social, moral and political types of knowledge they had identified and discussed. The identification of areas of uncertainty and the various levels of controversy of the SSI discussed indicates, students' ability to identify and embrace 'the complex relationality' (Elam et al., 2019, p. 63) of the different knowledge types and relations between actants involved in the particular controversy. For instance, both groups identified the relations between, and uncertainty around public health and the transmission and infection process, as

well as the links and uncertainty between public health and vaccination as a possible solution. The collaborative nature of the mapping task facilitated the sharing of students' personal perspectives, and provided space for reflection on the differences and tensions between such perspectives (e.g. population control vs valuing animals); the mapping task functioned as a discourse space where students could find their own voices (Balgopal et al., 2016). Students showed commitment in finding a solution, which facilitated co-construction of understanding, and a space for interrogating positions in a critical but constructive manner, for instance through questioning each other during their map constructions (e.g. Tables 4 and 6).

During the second mapping task, we observed a shift in the types of actants students included in their cartographies, indicating that these were conceptually enhanced from Map 1 to Map 2, for both groups. We consider this conceptual shift an indicator of students' developed understanding of the complexity of the badger-cattle controversy as they engaged in an exchange of views about the controversy, since actants that were tentatively discussed and framed with uncertainty in students' discussions during the first cartography task (e.g. scientists, vaccinations) but not included on their cartographies, were then included as actants in the second maps. As a result, both groups provided a more complex visualisation of the controversy in the second mapping task.

Using CoC within a pedagogical approach for SSI-based education

By asking students to record questions arising as they familiarise themselves with the controversy, the mapping activity allowed students to identify what they did not know and made them aware of their own uncertainties about the issue. As Ford (2015, p. 1046) notes, 'being able to reflect on what one knows, where uncertainties lie, and how these uncertainties can be translated into problems to solve is key to setting the stage for achieving intellectual progress – on any issue'. In our study, the cartographies acted as a tool for reflection; this opportunity for reflection on what is and what is not known provided affordances for students in both groups to engage in inquiry (e.g. the inclusion of 'further research' by Group A and 'scientists' by Group B), a key dimension of socioscientific reasoning, whereby they acknowledged the issue investigated as 'ill-structured' and as requiring further research and scrutiny (Romine et al., 2020; Zeidler et al., 2019). Further, we found that the framing of the discussion during the map construction and the actants included on the maps were not always presented with the same significance. For instance, Group A only included 'economy' with one connection on their Map 1 construction (Table 1), although one of the main ways in which they framed the issue during their discussion was the cost-effectiveness of the culling and how this affects the farmers' livelihoods (Table 3). At the same time, the nature of the discourse during the two mapping tasks was different, compared to the cartographies produced. During the first mapping task, students' discourse is rich, and students work together to explore the issue; in the second map construction, Map 2 provides a more complex representation of the SSI compared to Map 1, but the discourse is not as open and exploratory as previously, with students in both groups adopting a 'taken-for-granted' approach to the construction of their cartographies. Students were given the same instructions during the second mapping task; however, their discourse indicates that they mainly focused on procedural aspects of constructing the map rather than

exploring and agreeing on the actants to include on it. Therefore, the way in which the issue is framed by students during the deliberation is as important to consider as the cartography produced, and both need to be utilised in a complementary manner in future research and practice.

From a methodological and pedagogical point of view, we argue that considering the cartographies produced as stand-alone products, would provide a static and one-sided conceptualisation of the controversy, and does not provide an insight to the values and assumptions that students express or hold as they engage with the task. However, considering the cartographies as dynamic tools, encouraging students to co-construct controversies and to pose questions during this process can provide them with the skills needed for a more holistic exploration and visualisation of the controversy.

Overall, we found that the cartographies created collaboratively by students had multiple functions and uses within the pedagogical approach, and at different stages of the students' communication, as summarised in Figure 3.

The process of visualisation within the CoC approach can facilitate collaborative and participatory processes and can trigger discussion about the controversy (Schoffelen et al., 2015; Venturini, 2010). For our two groups, we found that the cartography functioned as a visualisation tool providing an insight into what students considered important in this controversy. At the same time, it functioned as an observation tool since as students added stakeholders and actants to their maps, they observed and discussed their importance, place and function within the controversy; consequently, they could identify further connections, new stakeholders, and tensions among various perspectives (e.g. Group A raising public health concerns led them to searching online for further information on the issue). This perspective-taking process of collaborative analysis of the

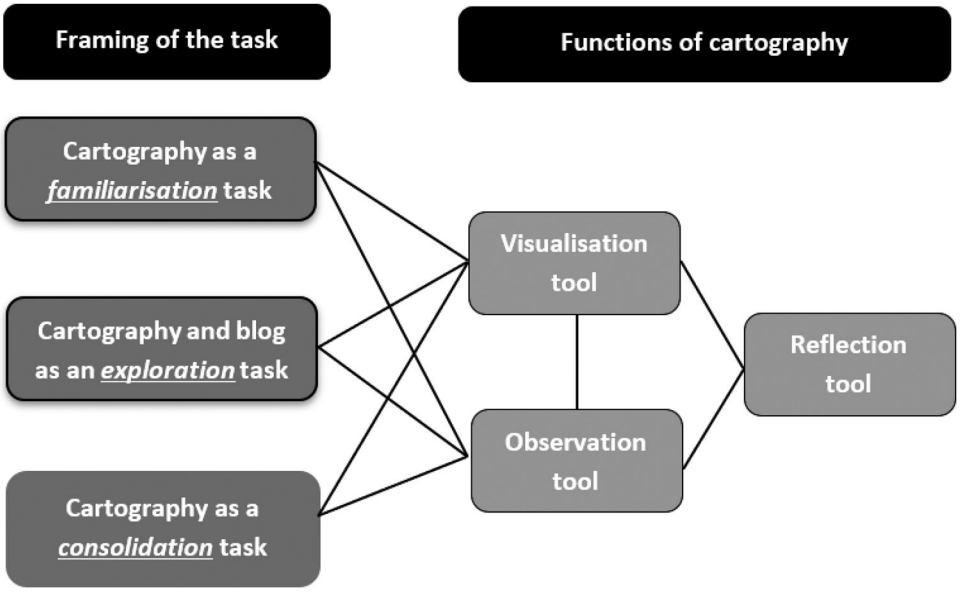

Figure 3. The framing and functions of cartography construction identified within our pedagogical approach.

controversial issue, constitutes another key dimension of socioscientific reasoning (Romine et al., 2020; Zeidler et al., 2019). Adding to the visualisation and observation functions of cartographies, we found that when the CoC is used within pedagogical contexts as in our study whereby students are encouraged to identify questions they can further investigate, the cartography functioned as a tool for reflection, triggering further learning through exploration or consolidation of existing understanding (e.g. through Group B reaching consensus on the risk to public health; through Group A students discussing on the blog the key themes of transmission and treatment identified during their first mapping task – Table 3).

The examination of how students approached the analysis of the badger cull controversy, revealed that both groups' approaches to solving the same task differed depending on the stage of their investigation and on the function of the cartographies at that stage in time. When the badger-cattle controversy was introduced to the students, their approach to solving the task took on the form of familiarisation, during which mapping the controversy was used as a visualisation and observation tool for students to explore their knowledge, ideas and positioning in relation to the SSI. When students were given the opportunity to continue explaining their views and analysing the issue during the blog communication, their approach became more exploratory discussing uncertainties raised (e.g. through questions) during the first map construction more in-depth, making their maps tools that facilitated observations of, and reflection on the issues identified. Finally, the second mapping activity seemed to function as a consolidation task, with students using it as an observation and visualisation tool for representing their new understanding of the badger-cattle controversy.

Conclusions and further research directions

The current study contributes to our understanding of how students can engage productively in SSI-based discussions within a pedagogical approach based on CoC. In this study, the use of CoC as a pedagogical approach allowed students to focus on what they knew, i.e. the actants identified and how these actants were interconnected, providing empirical grounding within a classroom-based setting to the theoretical discussion of CoC as a tool for observation and visualisation (Venturini, 2010). Further, our study's contribution includes the identification of reflection as an additional tool of the CoC approach, all of which can support students' deeper engagement with socioscientific reasoning. The use of the cartography as a reflection tool *during* the co-construction process allowed students to reflect on their knowledge, values and positioning *in action* and should be considered further in work that employs the CoC approach within classroom-based settings.

Within the limitations of a small-scale qualitative study with Biology students, the qualitative analysis illustrates the educational potential of the CoC approach, and how it can be adapted and adopted within a secondary school classroom setting to provide teachers and researchers with an insight into students' conceptualisation and understanding of the complexity of a SSI. Further research in this area could address this limitation by exploring how non-specialists, as well as younger learners, engage with the CoC approach within SSI-based education. Another limitation to acknowledge and address in further research is group cohesion and dynamics when students are constructing their

cartographies (e.g. who determines what is recorded on the cartography), and discussing the issue (e.g. who leads the discussion) as this might impede or facilitate student engagement with each other, and with the controversial issue.

Our study has also contributed to the exploration of the pedagogical potential of the CoC approach by identifying the various forms that the nature of the task (familiarisation, exploration, consolidation) and the function of the cartography (observation, visualisation, reflection) can take within an educational setting. The nature of the tasks and functions of controversy identified in our work can be utilised to design learning environments, which can enable students to realise the complexity of the issues explored through visualisation and observation within everyday science teaching. Further, by identifying questions to further explore as they construct their cartographies, students are encouraged to reflect on what is and what is not known. This can support students in making visible the complex relationality of actants involved in a controversial issue, and consequently, it can provide a starting point for supporting students in further engaging in socioscientific reasoning and dealing with complex, controversial issues (Zeidler et al., 2019). This means that the relational possibilities afforded by the CoC approach can be utilised *in practice* to support students' engagement with socioscientific reasoning.

Finally, recent research by Romine et al. (2020) on students' socioscientific reasoning indicates that the SSI dimensions previously identified could form a progression, with perspective-taking as a necessary bridge to dimensions such as complexity and inquiry. The use of the CoC approach as a visualisation, observation and reflection tool was found to be able to scaffold students' engagement with complexity within SSI-based education, as well as perspective-taking and inquiry dimensions of socioscientific reasoning. Further research on how to utilise the pedagogical potential of the CoC approach illustrated in our study could focus on how mapping controversies support students' engagement with all dimensions of socioscientific reasoning and the interplay of these dimensions.

Note

1. Actant is used to refer to both human (e.g. scientists, farmers) and non-human participants/concepts (environment, bTB) within a controversy rather than 'actor' that would typically refer to only human participants.

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