Introducing scientific argumentation practices in physics teacher’s undergraduate curricula

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Abstract. Recent educational research has suggested that introducing argumentation practices in science classrooms is an important approach to reach the goals of SSI education. However, it is safe to state that few undergraduate students have had the chance to engage in such practices during their time of formal instruction. With this in mind, this paper aims to present a case study about the introduction of argumentation practices that has been carried out with the participation of seven undergraduate Physics students of a public university in the state of Sao Paulo, Brazil. The debate was conducted as a simulated public hearing session, in which students were grouped in pairs and each pair was called to interpret a different social group involved in the Brazilian nuclear plan issue. The analysis was done using a recent methodology developed especially for argumentation exchanges in classrooms. While mediating the debate session, it was possible to notice a deep immersion in the role-played characters and a wider understanding of the social, economic and political issues involved in the nuclear area of Brazil.

1. Introduction

In this text, we advocate for the inclusion of socioscientific issues (SSI) debates in Physics teaching undergraduate programs by incorporating argumentative practices to pre-service teacher education. In order to do so, it is necessary to briefly define SSI and to distinguish it from a related research topic: Science, Technology, and Society (STS) education. According to Zeidler and Nichols [1], SSI “involve the deliberate use of scientific topics that require students to engage in dialogue, discussion, and debate. They are usually controversial in nature but have the added element of requiring a degree of moral reasoning or the evaluation of ethical concerns in the process of arriving at decisions regarding possible resolution of those issues” (Zeidler and Nichols, 2009, p.49). Zeidler et al. [2] make an important distinction between STS and SSI by stating that “while STS education typically stresses the impact of decisions in science and technology on society, it does not mandate explicit attention to the ethical issues contained within choices about means and ends, nor does it consider the moral or character development of students” (Zeidler et al., 2005, p.359), lacking of clear sociological and developmental theoretical basis. By including SSI in science classrooms through the development of argumentative practices, we assume a
pedagogical strategy that seeks to promote students’ cognitive and moral development [2] and also shift the underlying design principles of classrooms [3] from an authoritative and non-dialogic teaching approach to an interactive and dialogic teaching approach [4].

In the past few decades, the amount of research about argumentation in science classrooms and SSI has grown substantially, both quantitatively and qualitatively. Nevertheless, most of that research has explored issues that deal with primary, secondary and high school education. We acknowledge the importance of investigation in those levels, but we also note that the person responsible for proposing and guiding debates on SSI in science classrooms will always be the teacher. In argumentative contexts, “actions that approximate students’ conclusions to the agreed knowledge highly depend on the teachers’ mediation” (De Chiaro and Leitão, 2005, p.350). Therefore, our investigation aims at filling a gap in this area by capturing some of the particularities of teaching the skills of argumentation to university students, particularly to pre-service Physics teachers and trying to understand which elements in this Physics undergraduate program could be modified in order to include SSI as an integral part of class plans. As well pointed out by Jiménez-Aleixandre [3], “learning the practice of argumentation is part of the goals of constructivist science classrooms, where the roles of students and teachers are to be redesigned to scaffold students’ progressive assumption of responsibility, to model and guide inquiry and the criteria for assessment are to be publicly shared” (Jiménez-Aleixandre, 2008, p.93). Therefore, by conducting this investigation, we are also ensuring that those learning goals of constructivist science classrooms start to become a reality in universities in Brazil.

Introducing argumentative practices in university classrooms is not a trivial proposal. Based on the intrinsic controversial nature of SSI due to competing views held by different parties and the degree of uncertainty involved in many of these issues [6], the establishment of argumentative practices seems to be a natural consequence in terms of didactic proposals. However, it is necessary to create the appropriate conditions for the debate to emerge and to be maintained, conditions defined by [7] as interlocutor symmetry and diversity of opinions. Besides, justifying a claim based on facts and data and reflecting upon the basis on which our knowledge stands are actions seen as a higher-order mental processes [8], with metacognitive status highly desirable to be developed by students [9]. In this respect, many of the opinions defended by students in classrooms are not based on rational grounds but, instead, on religious, philosophical or cultural beliefs. So, to promote argumentation in classroom is an exercise of walking the tightrope: while presenting controversial topics that might bring up facts and data that introduce the scientific point of view for a certain subject, one must also deal with handling different opinions and beliefs in a civilized manner, an analogy to what happens (or, at least, should happen) in every democratic society. In the words of Simmoneaux [6], “there is a diversity of goals in dealing with SSI: to improve knowledge understanding, to contribute to citizenship education, to help students to make informed decision, to empower them to participate in debates, to help them to be able to deal with complexity, and to understand better the NOS” (Simmoneaux, 2008, p.181). When choosing from one or many of these goals, teachers (or researchers) will use different methodologies to conduct the activities and to analyse the obtained data. In the following lines we delimitate our study’s methodology and our main focus of analysis.

2. Methodology
The study here described could be framed as a qualitative educational case study [10] with the participation of seven last-year undergraduate Physics students and one university professor from the Education Department of a public university located in the state of São Paulo (Brazil) who teaches the obligatory course Didactics of Science to 7th-term undergraduate Physics students. The chosen SSI for this investigation concerned some perspectives for the Brazilian nuclear plan, with special attention to issues that are specific to the municipality of Angra dos Reis, a city located in the southern part of Rio de Janeiro.
state, home of the three main Brazilian nuclear plants. Students were grouped in pairs (one of them had to work alone) and each pair was called to interpret a social agent or group directly involved with the Brazilian nuclear issues. This didactic strategy referenced as educational or academic roleplay “is one of the more frequently used active learning instructional strategies currently being used at the American university level in the preparation of future educators” (Crow and Nelson, 2015, p.26) and it has already been incorporated into Brazilian academic research that deals with argumentation in classroom [12]. The four social groups roleplayed in this study were: 1) citizens of Angra dos Reis; 2) political representatives in charge of law-making and executive actions regarding national energy plans; 3) business executives in charge of Angra dos Reis’ nuclear power plants and; 4) members of the Brazilian Physical Society. Those four groups were pre-defined by the researcher and the professor, but the students were free to elect the personal details (fictional name, social class, occupation etc.) of their characters. The debate was conducted as a simulated public hearing session, with the researcher acting as the debate mediator and the students speaking in turns of about 2 minutes each. Students were asked prior to the debate to search for any source of information regarding the chosen SSI, since we also expected to notice what do students counted as valid information sources for this issue. On the day of the debate, students sat in a semi-circular formation facing the researcher. Data was collected using video recorders. The main focus of our analysis was to understand whether the arguments presented in the debate reflected the students’ own opinions or the roleplayed characters’ voice about this issue. The analysis was conducted using a theory-based method developed by Vieira [13], a method that specifically addresses argumentation discourse in science classrooms and that: 1) allows us to characterize the argumentative discourse and distinguish it from other discursive orientations present in classroom; 2) considers the didactic intentionality as a classroom fact, relating what teachers say in their contexts with each one of their didactic goals; and 3) defines the discursive procedures (DP) as “[...] a set of propositions that have a convergent meaning” or as propositions that “do the same thing” and uses concepts from Text Linguistics to segment participants’ claims into propositions (smallest units of meaning) and group propositions with convergent meaning into discursive procedures for teachers and students. This method incorporates concepts from three important theoretical pillars: 1) Activity Theory [14]; 2) Interactional Sociolinguistics [15]; and 3) Text Linguistics [16-19]. Each of the three pillars of the methodology produced tables that constitute the text corpus of this research: 1) Propositional table, based on the propositional speech segmentation [15]; 2) Class description table, based on concepts of motivations, actions and goals from the Activity Theory [14] and; 3) Narrative table, the most complete analysis instrument that allowed us to map the mediator’s actions, the discursive orientations, the emerging topics and patterns and functions in the discursive procedures used by the debate mediator. Unfortunately, the scope and the extension of this paper will not allow us to present detailed information about all three tables. Thus, we have chosen only one propositional table as our main analysis instrument.

3. Collected Data and Analysis

Table 1 below contains a short excerpt from the simulated public hearing activity about the Brazilian nuclear plan. In this excerpt, students A1 and A5 are roleplaying, respectively, the Minister of Science and Technology and one of the director of the Brazilian Physical Society. They are discussing an issue that became quite popular for its political and economic implications in the Brazilian nuclear energy scenario a few years ago. As stated above, each speech turn lasted for approximately two minutes. Propositions were created based on the discourse segmentation in units of meaning [15-19] and the discourse procedures were mapped and listed following the methodological guidelines of [13].

Table 1. Propositional table with an excerpt from the debate about the Brazilian nuclear plan.
| Speech Turns | Propositions (Units of meaning) | Discourse Procedures (DP) |
|--------------|---------------------------------|---------------------------|
| 1. Mediator: | 01. Miss Sophie, 02. Before we give the floor to any other person who may want to speak, we have a question here sent by the audience. It reads: 03. “In the last few years, Brazil has considered the chances of establishing partnerships with countries who would like to develop their nuclear military technology. One of the countries with which Brazil started to get into discussions was Iran. As the Minister of Science and Technology, what is your opinion on this topic?” | 1. Interlocutor nomination 2. Clarification about a discourse procedure 3. Introduction of a new issue |
| 2. Student A1: | 01. In my personal opinion on this issue, 02. I believe that these relations must be established but with a lot of caution. 03. Uh, the issue of turning nuclear energy to military purposes 04. It has been present in Brazil since 1930 when in the beginning of the nuclear era in Brazil and it was precisely for military purposes 05. Of course that it is a topic that might bring discomfort and a certain repulsion by the society, for it represents danger, right? 06. But we musn’t think just about the risks, but also that 07. Brazil needs, in the first place, to be prepared for protection 08. We are in a moment, here in Brazil, that is not of war, 09. But we have already been through many others and, 10. We must be prepared if something happens again. 11. Uh, in Dilma’s government, we have, for example, the nuclear submarine project, which is an topic of interest to the very protection of the country. 12. So, I do agree, 13. I do not say I agree with Iran, neither with any other country, 14. But connections must be made, especially in order to make progress in our nuclear technology. | 1. Opening speech turn 2. Opinion emission 3-4. Adding historical information as backing 5-6. Considering others’ opinion to make rebuttal 7. Opinion emission 8-9. Opinion justification 10. Opinion emission 11. Adding governmental information as backing 12. Reaffirming opinion 13-14. Re-elaborating and re-affirming opinion |
| 3. Mediator: | 01. O.K., thank you very much for your contribution. 02. We then pass the microphone for those who would like to... 03. Yes, Mr. Alan, please. | 1. Mediator’s feedback 2. Clarification on DP 3. Interlocutor Nomination |

01. I would like to make an observation here, 02. I think that by establishing a partnership with another
4. Student A5:

country regarding military purposes,
03. We must be cautious and ask ourselves,
04. How will this partnership with military purposes bring scientific benefits to our country?
05. Because we must be careful when saying:
06. “O.K., let’s make a deal with that country because they are offering military technology”,
07. but actually that will not bring technological improvements for our country and we will end up giving them feedstock that they need.
08. So, we must be cautious and take this into account,
09. To what extent can our technology advance and be beneficial to the population?
10. Because it’s no use advancing and being bad for the country,
11. And one more caution,
12. that I believe to be more related to political issues,
13. which is not our area’s strong suit, but
14. it is about with what country are we establishing this partnership.
15. not to mention the fact that that country might be supplying scrapped technology,
16. and also the way that the global economy is going and all these relations that exist between the countries,
17. Be careful to not, for example, make a partnership with Iran and then look bad to countries that have much more technology to offer to us.
18. I think those aspects should be taken into account.

discussed issue
3. Opinion emission
4. Introducing a new issue
5. Opinion emission
6. Mimic a possible conclusion
7-8. Opinion emission
9. Introducing a new issue
10. Justification for an opinion
11&14-15. Introducing a new issue
12-13. Self-evaluation of the introduced issue
14-17. Introducing a new issue
18. Closing speech turn

We start our analysis by checking whether the excerpt above is an argumentative exchange or not. In order to classify such discursive exchange, we use the two aforementioned criteria called interlocutor symmetry and diversity of opinions, followed by their respective justifications [7]. We may affirm that there is interlocutor symmetry, since the participants are all university students in the same stage of their undergraduate course, they have all had the same time to prepare for the debate, there have all been given access to the same information resources and they have all been given practically the same amount of time to speak. They recognize each other as equals in the discourse exchanges. We may also affirm that there is diversity of opinions followed by their respective justifications, since student A1’s opinion (playing the role of the Minister of Science and Technology) seems to be aligned towards the need to establish new connections with other countries: “I do agree…”, “But connections must be made in order to make progress in our nuclear technology…”, while student A5’s opinion (playing the role of the Brazilian Physical Society’s Head Counselor) is more aligned towards not establishing that specific partnership by pointing to many aspects that demand attention and that should be treated with caution: “How will this partnership with military purposes bring scientific benefits to our country?”, “To what extent can our technology advance and be beneficial to the population?”, “not to mention the fact that that country might be supplying scrapped technology…”. The justifications for each one of these opinions are marked in the
column called “Discursive Procedures” in Table 01. Therefore, Table 01 represents an argumentative discourse according to the two criteria used in the analysis.

But how was this argumentative discourse created and maintained? Students in classroom naturally have different opinions about certain topics, especially when it comes to issues that involve moral, ethical, religious and philosophical dilemmas. However, in a classroom where students have been classmates for years and have developed a sense of partnership, disagreement and diversity of opinions might be implicit, and not explicit [20], for they believe that exhibiting these disagreements might undermine their relationships. In order to create enough tension to make these disagreements emerge, the teacher (or the researcher) may pose a question or a comment about a specific topic that will require students to make moral and ethical judgments. Before Speech Turn #01, students had not shown a single explicit disagreement, having emitted very similar opinions that complemented or illustrated each other. Thus, it was not considered an argumentative situation. The introduction of a “question from the audience” in Speech Turn #01, which had been previously prepared by the researcher, was an intentional move in order to explicit controversies in their opinions. From this moment on, the number of disagreements rose and the mediator’s action was more focused on controlling time and giving the floor to different students. Yet, students A1 and A5 explicited their opinions in quite different levels. Student A5 did not agree with the establishment of a partnership between Brazil and Iran, but he did not explicit his point of view straightaway. Instead, he repeated some sentences that posed a feeling of fear and distrust in the audience: “we must be careful” or “we must be cautious”. Besides, he introduced new issues containing very wide adjectives of moral judgement about the mentioned partnership: “beneficial to the population”; “look bad to other countries”; “being bad for the country” etc. On the other hand, student A1 stood her ground by explicitly affirming many times: “these relations must be established”; “I do agree”; “Connections must be made...” etc. It is one of the tasks of the mediator to notice if students perceived implicit disagreements, because if they did not, it is very likely that they will not engage in producing stronger justifications, rebuttals or counter-arguments. This is one of the moments when teachers may teach their students some of the rules to engage in an argumentative discourse without explicitly showing these rules prior to the debate.

About the effect that the roleplay dynamics had in the students’ argumentation, we would like to focus on Speech Turn #02 and #04. In Speech Turn #01, the audience question ends by asking for the opinion of the Minister of Science and Technology, roleplayed by Student A1. Nevertheless, Student A1 begins her turn saying: “In my personal opinion on this matter, I believe that...”, implying that she was no longer using her character’s voice to speak, but was actually stating her own opinion about the issue. In Speech Turn #04, student A5 says: “And one more caution, that I believe to be more related to political issues, which is not our area’s strong suit...”. Although student A5 spoke using pronouns such as “we” and “our”, it is clear that he was emitting his personal opinion on the significance of the Brazilian Physical Society in scientific topics that imply political decisions. As it is well known among the Brazilian scientific community, the Brazilian Physical Society was pioneer in the process of scientific modernization in the country, exerting an important influence in the creation of the first council of research and development and in defending the importance of science and technology in times of dictatorship, actions that costed the exile of many of its intellectuals. Thus, by saying that political issues are not the society’s strong suit, he was shifting his statement away from the consensus and probably re-affirming a well-known common sense view that places science and technology in a false neutral position, disconnected from political issues. We understand that the roleplay facilitated the immersion in the characters’ voices and allowed students to emit their own opinions more naturally, capturing some of their views about the nature of science (NOS), one of the aforementioned goals for argumentation classes about SSI [6].

It is also interesting to notice how some of the students’ opinions in this excerpt (and throughout the rest of the debate as well) actually impersonated events or situations that happened in real life with a
certain degree of realism. We affirm that because a central part of this research was based on gathering historical information from many sources and producing a commented retrospective about the Brazilian nuclear agenda plan, from its very first steps until the present time. One of the studies on this issue affirms that at the Nuclear Security Summit in April 2010, Brazil joined forces with Turkey – at the time, both were non-permanent members of the UN Security Council – and opposed new sanctions against Iran in the face of the controversial status of its nuclear program. Brazil showed that it hoped to act as a mediator between Tehran and Washington [21]. That means that, at the time, the Brazilian government did defend an opinion favourable to the establishment of these new connections. In the meantime, the Brazilian Physical Society issued a public statement on March 03, 2010, in which it stated: “We extern our worry with the news that bilateral agreements in the nuclear area between Brazil and countries which are not members of the Treaty on the Non-Proliferation of Nuclear Weapons (TNP) may be in analysis by the Brazilian government and we manifest our conviction that the Brazilian interests would be better represented if no technical or scientific cooperation were to be celebrated with the Islamic Republic of Iran” (SBF, 2010). We are still unable to affirm whether such “impersonation of real life” is an interesting coincidence or the result of a detailed information search done by the students that allowed them to impersonate real-life events accurately. A study that relates the types and the quality of information sources used by the students to their argumentation competences in SSI debates is a desirable development for our study and is already underway during the researcher’s doctorate thesis.

4. Conclusions

Students started taking into account important alternative information sources besides science textbooks and sensationalist webpages. A good example is that one of the students who interpreted the citizens of Angra dos Reis contacted ten people who actually live there by sending messages on their social network pages and explaining the need for more accurate information to prepare for a debate in his university. For students who have been used to collect all the information that they need from textbooks and handouts, it is an interesting development to see that they started considering the opinions of the lay public as something relevant in the process of decision making about a socioscientific issue.

The methodology used in this study was seen as very wide and powerful for the purposes of the study, allowing a clear distinction between argumentative and explanatory discourses with the usage of two specific criteria. This is still a big problem when implementing argumentation practices in classroom, since teachers, professors and students do not know very well the clear boundaries between those two different discourse orientations. This specific problem is the reason why sometimes people believe that they have engaged in an argumentative situation, when actually there was no justifications, rebuttals and counter arguments involved.

We believe that there is a possible association between the category of Discursive Didactic Procedures (DDP) and the diversity of possible goals for SSI classes mentioned above: to achieve different goals during argumentative classes, teachers and researchers will have to elaborate distinct discursive procedures based on the scientific literature and their past experiences applying this sort of activity. This may be a line for future research on this topic.

In summary, while mediating the debate session, it was possible to notice a strong immersion in the roleplayed characters that allowed students to sometimes have wider understanding of the social, economic, and political issues involved in the nuclear area of Brazil and, in other moments, permitted an easier expression of their own opinions and beliefs behind the voices of the roleplayed characters, opinions that can be used by teachers and researchers as a starting point to present a more modern and contextualized view of science and technology.

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