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Using a mock trial activity to study verbal argumentation skills in socioscientific issues

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ABSTRACT: We present a novel educational environment aimed at promoting argumentation skills and incorporating nature of science themes in the context of socioscientific issues. The study was conducted during chemistry lessons with 10th-grade students and comprised of three parts which are a set of lessons on the history of nuclear energy, preparation for a mock trial, and a mock trial activity involving students' participation. We analyzed students' arguments during the trial through the lens of two assessment frameworks: Toulmin's model of argumentation and informal logic fallacies analysis. Results showed that the intervention was successful in fostering a conducive argumentative atmosphere and had a positive impact on student learning. Our findings also revealed that the criteria for evaluating arguments according to Toulmin's model and informal logic fallacies analysis were not mutually exclusive; some arguments that met Toulmin's criteria were at the same time fallacious according to the latter framework. This raises important questions regarding the methodology of argument analysis in live discussions.

KEYWORDS: Argumentation, socioscientific issue, informal logic fallacy, mock trial, NOS.

I. INTRODUCTION

Argumentation has gained significant attention in science education as part of a shift towards student-centered pedagogies in educational systems worldwide (Schwarz & Baker, 2016). There are several reasons for incorporating argumentation in science classes, including the enhancement of scientific literacy. Scientific literacy, which includes critical thinking skills, is a major goal of many educational systems with the aim of producing scientifically literate citizens (Gut, 2011; Israel Ministry of Education, 2009; National Research Council, 2013). However, critical thinking remains a debated construct, and it is widely agreed that it involves high-level argumentation skills (Facione, 1990; Pithers & Soden, 2000; Science, 1994; Wertsch, 1991). Another aspect of scientific literacy is decision-making, which requires scientifically literate citizens to make informed decisions on science-related topics, both personal (What shampoo I should buy?) and social ("Should the government allow fracking in a certain area?") based on scientific knowledge and reasoning (Jime'nez-Aleixandre, 2002; Johnson & Blair, 2006; Kuhn & Udell, 2003; Schwarz & De Groot, 2007). A decision is a reasoned choice made between a number of alternatives according to a certain criterion (Kortland, 1996). Using scientific knowledge in everyday life decisions is not trivial and includes examination of data, comparison of different sources of information, considering the pros and cons and reflect on social vs personal benefits (Jime'nez-Aleixandre, 2002; Johnson & Blair, 2006; Kuhn & Udell, 2003; Schwarz & De Groot, 2007). Previous research has demonstrated that the implementation of argumentative environments can improve students' decision-making and reasoning abilities (Jime'nez-Aleixandre, 2002; Sadler & Donnelly, 2006; Simonneaux, 2007).

The second reason for incorporating argumentation in science classes is that it meets the epistemic criteria for evaluating scientific knowledge. This in turn, helps students gain a more comprehensive understanding of scientific procedures, processes, and their dynamic nature (Duschl, 2007; Nussbaum, Sinatra, & Poliquin, 2008; Sandoval & Millwood, 2005). The third reason is that argumentation through dialogue can facilitate the construction of scientific knowledge (Baker, 2009; Mason, 1996; Schwarz, Neuman, Gil, & Ilya, 2003; Stegmann, Weinberger, & Fischer, 2007).

Supporting argumentation in class

Giving the fact that argumentation rarely occurs spontaneously in class and is difficult to sustain, calls for a unique design that will permit the establishment of norms of argumentation (Andriessen & Schwarz, 2009; Berland & Reiser, 2009; Driver, Newton, & Osborne, 2000; Jiménez- Aleixandre, Bugallo Rodríguez, & Duschl, 2000). Next, we give some notable examples of works, that have suggested some design principle to support argumentation in class. Jimenez (2008) suggested six design principles for appropriating the practice of

Argumentation in the science class; 1. The students are active producers of justified knowledge, 2. The teachers act as facilitators and navigators in the class, 3. The curriculum design should support inquiry and argumentation, 4. The students will share the criteria for arguments and knowledge assessment, 5. The students will be engaged in the reflection of their arguments and others as well, 6.The design will establish a dialogic and interactive discourse in the class. Schwarz and Asterhan (2010) give three prior conditions for productive argumentation in class; 1) Maintaining teacher student interactions, 2) Have a mental model or strategy for the task at stake, 3) Avoid social inhibition that might be caused by disagreement. Berland and McNiell (Berland & McNeill, 2010) suggested a learning progression model that implements argumentation over a long period from k-12, describing in detail a scaffolding which decreases over time. Osborne et. al (Osborne et al., 2016) suggest a three-tiered learning progression based on the intrinsic cognitive load of the argument. The assessment of the argument complexity is based on Toulmins' model. In these works, and many others, we notice two major characteristics which are crucial for implementing argumentation a) Establishing a safe zone in which students will feel free to express themselves, b) shift teachers towards student centered pedagogy.

To foster a productive argumentation environment in the science classroom, students must feel safe to express their opinions without fear of judgment (Driver et al., 2000; McNeill & Pimentel, 2010). Effective teaching strategies to encourage argumentation include consensus project models (Koltso, 2000), debates and decision-making regarding socioscientific issues (Albe, 2008; Simonneaux, 2001; Zohar & Nemet, 2002), and the jigsaw classroom approach (Aronson, 2002; Eilks, 2005).The implementation of argumentation requires a shift from a teacher-centered to a student-centered pedagogy, where the teacher acts as a facilitator rather than a lecturer. The teacher should actively listen to student arguments, encourage clarification and refinement, and support the use of data to support their arguments (McNeill & Pimentel, 2010; Sampson & Blanchard, 2012). The use of technology to facilitate argumentation may also be beneficial (Clark et al., 2007; Pinkwart, 2012). It is crucial for teachers to explicitly encourage student participation in the class discourse (Herrenkohl et al., 1999).

SSI, NOS and argumentation: The integration of socioscientific issues (SSI) in science education has been shown to enhance students' argumentation skills and understanding of the nature of science (NOS). A number of studies have reported positive outcomes of using SSI as a context for science teaching, including improved students' understanding of NOS and the epistemology of science, as well as an increase in the number of arguments generated in class discussions (Kolstø, 2006; Sadler, 2006; Zohar & Nemet, 2002; Dankert, 2006; Osborne & Chin, 2010; Zeidler et al., 2002; Sadler & Dawson, 2012; Sadler & Zeidler, 2005b; Achwartz et al., 2004; Eastwood et al., 2012).

However, it has also been noted that students often struggle to articulate well-supported arguments when working with SSI (Driver et al., 2000; Simonneaux, 2008). One possible explanation for this is the transfer of scientific knowledge from a technical to a social context, which requires students to integrate two types of discourse (Schwarz & Baker, 2016). To overcome this challenge, it is important to design lessons that align with curriculum needs and choose SSI that are relevant to the topic being taught.In this paper, we present a design for SSI argumentation that we have developed, implemented, and evaluated in a high-school science lesson. Our findings demonstrate the effectiveness of this design in fostering NOS and argumentation skills simultaneously. We aim to provide a practical resource for argumentation and NOS research and for teachers and professional development designers.

Assessment of argumentation : In recent years, various methodologies have been proposed to assess argumentation in science classrooms. One widely adopted approach is the use of the Toulmin model of argumentation (Jiménez-Aleixandre et al., 2000; Kelly, Druker, & Chen, 1998; Simon, 2008). Erduran, Simon, and Osborne (2004) developed the "Toulmin's Argumentation Pattern" (TAP) analysis, which assesses arguments using a coding scheme based on the Toulmin model. Bernard and McNiell (2010) later proposed a simplified version of the Toulmin model, including only three elements of an argument: claim, evidence, and reasoning.

Simmoneaux (1996) used Bronckart's four categories of modalization to compare arguments between two student groups. Some studies have applied informal logic schemes to evaluate students' arguments, such as Duschl (2007), who used Walton's argumentation schemes for presumptive reasoning (Walton, 1996), and Zeidler and Sadler (2005a), who used the neo-Kolberian theoretical framework of moral reasoning. Other studies have used informal logic fallacies as a framework, such as Jungwirth (1987), Neuman (2003), and Weinstock, Neuman, & Glassner (2006).Recently, researchers have placed greater emphasis on examining discourse characteristics, instead of solely focusing on argument structure. This shift is based on the belief that a narrow focus on arguments distracts researchers from the context and interactions between students and teachers (Nielsen, 2013). However, a comparative assessment of argumentation, encompassing both Toulmin's argumentation pattern and informal reasoning, is currently missing from the literature.

Research Goals and Questions : In this study, we analyze students' argumentation skills during a mock trial activity in a chemistry class. To evaluate the students' arguments, we employ two approaches: Toulmin's model of argumentation and informal logical fallacies. Additionally, we describe the design of our lessons that aimed to create a stimulating learning environment that encouraged argumentation. The design had three major goals: (i) to develop a learning setting that integrates Nature of Science (NOS) concepts into the context of Scientific and Technological Issues (STS), (ii) to choose topics that are relevant to students' lives and align with the current chemistry curriculum, and (iii) to facilitate debate, discussion, and argumentation. Our lesson design is divided into three parts: a lesson presentation, student preparation, and the mock trial activity. In particular we ask:

- To what extent the learning environment supported argumentation?
- What was the quality of students' arguments?

II. METHODS

Study overview : The aim of the study was to explore (a) the type, and (b) the quality of the arguments that two classes of students have formed during a 'mock trial that followed a thorough didactic design and to examine whether a so-called adversarial activity could be an example of a supportive environment for argumentation. Prior to the mock trial students had a sequence of lessons that served as a preparation to meet pre-conditions for a productive argumentation environment, with a focus on a) acquiring sufficient knowledge about the issue, b) establishing norms of argumentation in the class, and a safe zone for students to speak up, and c) using an engaging context. To meet those conditions students experiences a sequence of lessons accompanied by a presentation on the history of nuclear energy , followed by a preparation for the mock trial.

Participants : The research sample consisted of two classes of 10th-grade students (aged 15–16 years), from two different schools in different cities in Israel, who had studied a basic introductory course in chemistry, and considered to be above average students. Class Y2 consisted of 30 students while class, K, had 16 students. The students came from a moderate socioeconomic background.

The learning environment: We would like to emphasize that the focus of this study is on students' argumentation during the mock trial, however the context and the prior lessons to the mock trial are an integral part of the outcome and therefore we believe it is important to elaborate on the pedagogical design prior to the mock trial.

Lessons accompanied by a presentation: The lessons were accompanied by a Prezi presentation (Prezi.com) which embedded video clips. The presentation took advantage of the Prezi nonlinear designing options. We designed the whole presentation as a clock, in which experiments, historical and scientific events, were presented chronologically. This form of presentation allowed us to easily jump between years and events, letting students be more aware of the historical timeline and hence perceive science tentativeness in a robust manner. We thought that this design would allow a storytelling format that progresses from one lesson to the next (Stinner, 1995; Tao, 2003). The lessons discussed historical events and scientists' responsibility for those events. We embedded in the lessons questions that were open to a discussion such as: “According to what criteria you would judge a scientific discovery?”. The presentation’s storyline starts with an introduction to the famous formula Albert Einstein revealed, $E = mc^2$ and its theoretical foundation for planning the atomic bomb. We placed in the context of Iran’s nuclear program which serving as a hook for capturing students' attention and engaging them in the lesson (LaBar & Cabeza, 2006; Pessoa, 2008). The basic chemistry scientific content which is part of the 10th-grade curriculum was embedded in the presentation as part of the “storytelling.” Concepts such as atomic structure, isotopes, conservation of mass and energy, radioactivity, and nuclear reactions were presented were introduced to the students via different historical episodes telling the story of marvelous scientific endeavor, that resulted in both gratifying and horrifying outcomes for humanity. For example, we introduced the discovery of conservation of mass and energy by describing Priestley and Lavoisier's experiments, further explaining how they supported Dalton in writing his laws. We moved forward in time to the discovery of subatomic particles by describing Thomson and Rutherford's experiments and models of the atom and then went back in time to Becquerel's discovery of radioactive matter, following the work of Marie Curie. The design of the presentation's content is not the central issue of this paper, but the back-and-forth movement through historical episodes, personal stories, and experiments enabled us to tell an authentic story that captures the drama involved in decoding the atom and making a strong case for the impact the scientific enterprise has on human history. along with the scientific concepts and ideas, were part of the story's flow.

The presentation was scheduled to take place after the students had learned about atomic structure. At that point, the scientific content was presented in context, so they could relate the scientific content to the historical events behind those discoveries and their impact on humanity. We tried to make an abstract topic, such as the atomic model and radioactivity that were shown to be particularly challenging for students (Griffiths & Preston, 1992; Ruth Ben-Zvi, 1985) more concrete by addressing relevant current issue and investigate it from a scientific and a historical perspective.To evoke a discussion in the class and within groups, we embedded questions throughout the presentation. After such a discussion the teacher summarized the points of agreement and differences in the discussion. Those questions were a first step in engaging students in argumentation over SSI.

Student preparation : Following the historical science lessons, the students prepared for the mock trial. The class was introduced to a scenario in which citizens in a real city in Israel who live near a nuclear reactor sue the state to demand its transfer to a safer zone. The teacher divided the students into groups with assigned roles: prosecution and defense lawyers, prosecution and defense witnesses, jury members, with the teacher serving as a judge. Each group were given three academic hours to prepare for their role during which they were tasked to build arguments and look for data to support them. More specifically, each received a worksheet with guided question to support in collecting data, sorting evidence into scientific or non-scientific, preparing for counter arguments, and reflection. For example: the lawyers were asked to think about what the opponent's arguments might be and what their response might entail. The witnesses were asked to raise questions they thought they would be asked during the trial and plan their answers accordingly. The jurors were asked to collect as much background data as possible so that they would be up to date on the facts presented to them during the trial. The teacher served as a resource for the groups and supported them in making a more efficient search on the web which students had a full access to during the preparation. It is important to note that the teacher did not help the students to form their arguments. The mock trial provides an environment that enables students to debate in a structural manner, However, the incentive of competition can lead to the trail turning into an emotional quarrel. Therefore the students were presented with explicit set of rules for the trial. Additionally, the teacher advised both the prosecution and defense teams to remember that their goal is to convince and influence the jury's appraisal of the evidence.

Mock trial activity: Researchers have used both debate and mock trial activities to encourage argumentation, and neither has been found to be more efficient than the other (Simonneaux, 2008). In this study, we chose to utilize a mock trial activity for several reasons Firstly, the longer duration of the mock trial activity allows the coverage of more perspectives and information. While the length of the mock trial could also be viewed as a disadvantage, the circumstances of the study allowed for a sufficient time investment in the activity. Secondly, the social nature of the mock trial, provided all students an opportunity to participate. Thirdly, the focus on one dilemma, reduces the chances of distraction. And fourthly, the theatrical nature of the mock trial, in which some of the students get to act out a role, generates enthusiasm and engagement. The mock trial was simplified as much as possible and followed the structure of opening speeches, witness testimony, cross-examination, closing speeches, and finally, jury discussion and decision. The issue students debated, was related to the lessons accompanied by the science history presentation, so concepts such as nuclear fission, isotopes, radioactivity, radioactive decay, served both sides of the argument during the trial.

Pedagogical considerations: The activity is based on a controversial issue that provides the students an opportunity for reflection, consulting with their peers, and finally, achieve an autonomous opinion. Because the issue has no true or false answer, it encourages different points of view and welcomes a wide range of scientific evidence. The design of the activities aimed to promote the formation of diverse arguments. To achieve this, two conditions were established: (i) the provision of a rich background that would provide ample data for constructing well-supported arguments and (ii) an environment that fostered debate and encouraged diverse perspectives. The students were introduced to a variety of scientific, historical, and moral information through a series of lessons on the history of nuclear energy. This structured approach, in accordance with Koslowski (1996), facilitated the development of arguments that were firmly based on the available data and information. The intervention was carried out within the context of a chemistry lesson, seamlessly integrating scientific concepts and discoveries with real-world historical and moral questions. The relationship between scientific work and human endeavors was emphasized, demonstrating their impact on the course of history and the lives of students (Abd-El-Khalick & Lederman, 2000). Moral considerations were also addressed, providing students with the opportunity to reflect on the impact of the scientific enterprise and to consider questions without a clear-cut answer.

We encouraged debate and a pluralistic environment by embedding questions throughout the presentation that raised a conflict. For example, more ethically oriented questions were: "To what extent do you think social norms impact scientists' research and behavior?", "If you were a scientist during World War II, would you agree to be part of the military effort and weapon development?", "What do you think about scientists who worked for the "Axis" countries?". More scientifically oriented questions are: "Where did the forest disappear?" (after showing them before and after pictures of a large forest in which a recent fire occurred), "Do you think vacuum conducts electricity?" (after watching the cathode ray experiment). All lessons included a plenary discussion, or group discussion and reflection, scaffolding a pluralistic environment for the mock trial.

III. DATA COLLECTION

Mock Trial video recording and transcription: The mock trial in each class was video recorded and fully transcribed. Both mock trials, lasted for nearly five consecutive academic hours (3.5 hours). We segmented the transcript according to the trial structure as followed:

- Prosecution's opening speech
- Defense's opening speech
- Prosecution’s witness interrogation
- Defense's witness interrogation
- Prosecution's closing speech
- Defense's closing speech
- Jury consultation

Interviews: We conducted interviews with a sample of students who agreed to take part in the interview, and whose parents approved their participation in writing. The interviews were conducted by our colleagues in the Department of Science Teaching to avoid bias. Structured interviews were used to maintain as much coherence as possible between the interviewees. In total, we interviewed ten students, six from class Y2 and four from class K. Interviews were recorded and fully transcribed. Each interview lasted 20 minutes on average.

IV. DATA ANALYSIS

Assessing arguments during the mock trial : Each part of the mock trial structure was segmented further to five-minute segments (Shkedi, 2003). Arguments were identified throughout the transcript. An argument was considered as such if it contained at least a claim or a conclusion. Then each argument was analyzed according to Toulmin's model of argumentation (Toulmin, 1958). Note that all the arguments were considered as supporting arguments for the prosecution or defense's primary claim and motion of the trial (whether the government should or should not transfer a nuclear reactor that is placed in proximity to a populated city). Accordingly, each argument was analyzed in the context of the motion of the trial. As part of the analysis, the arguments were sorted into different pre-defined categories:

- An argument with no basis – an unjustified claim or conclusion
- A valid scientific argument – an argument that is scientifically based and includes at least: claim and scientific evidence.
- An argument that is based on partial or erroneous scientific evidence and includes: claim, and partial or erroneous scientific evidence.
- Sound arguments not related to science explicitly and include at least: claim and supporting evidence.

  Arguments in this category pertained more to ethics, political affairs, historical precedents, and so forth.

  In order to thoroughly analyze the students' argumentation skills, we expanded the categories of arguments to include those that did not fit into the initial categories. One such category was "rebuttals", which were identified as arguments that challenged and contradicted arguments presented by the opposing side. Rebuttals were treated as a separate category because they were not always immediately presented in response to an argument, but rather, were addressing and argument that came earlier in the trail. The mock trial environment encouraged counterarguments and the use of data to support these challenges. Through this analysis, seven categories of argumentation were established.

- An argument with no basis – a claim with no support whatsoever
- An argument that is scientifically based – a claim based on a scientific evidence, expertise, experiments, or scientific explanations.
- An argument based on partial scientific evidence – a claim that relies on scientific themes but with no supporting data or explanations.
- An argument based on erroneous scientific data – a claim supported by distorted or erroneous scientific explanations that don't agree with a canonical understanding of scientific concepts.
- An argument that is based on but does not explicitly address science – claim, and supporting evidence. Arguments under this category pertained to ethics, political affairs, historical precedents, etc.
- An argument that does not explicitly address science and is based on erroneous evidence.
- Rebuttal – counterarguments based at least on claims and evidence.

Adopting the view of Schwarz and Baker (2016) that perceives argumentation in science as different from that in other disciplines, we are differentiating scientific and non-scientific arguments to determine the extent to which students can harness scientific knowledge to articulate arguments in a socioscientific context. A first analysis noticed arguments that are manipulative and lacking logical coherence. To address those types of arguments, in addition to Toulmin's criteria, we searched for informal logic fallacies in students' arguments (Johnson & Blair, 2006; Walton, 1989)."In our analysis of fallacious arguments we focused on categories previously referenced in the literature (Zeidler, Lederman, & Taylor, 1992; Zohar & Nemet, 2002). Table 1 presents the fallacies addressed in our study. To examine logical fallacies in students' arguments, we analyzed transcript segments of their arguments. We categorized the fallacies into three main groups: irrelevance fallacies, fallacies of presumption, and ambiguity fallacies (Walton, 1987). Irrelevance fallacies involve arguments where the conclusion does not follow from the premises presented. Fallacies of presumption rely on false or unwarranted assumptions, thereby failing to support the conclusion. Ambiguity fallacies result from imprecise and unclear language use."

Table 1 Fallacy types

Irrelevance fallacies			**Presumption fallacies**			**Ambiguity fallacies**		
Name of fallacy	Short definition	Example from the mock trial	Name of fallacy	Short definition	Example from the mock trial	Name of fallacy	Short definition	Example from the mock trial
Relies on ignorance	When ignorance is exploited to prove the truth of a claim.	*"We don't know if a leak in the nuclear reactor will cause the same impact as in Fukushima, so we can say that the reactor is safe."*	Begging the question	When the justification and data are articulated in different words of the claim or conclusion.	*"We need to close the nuclear plant. Otherwise, it will be a great mistake."*	Ambiguity	When an unclear phrase with multiple definitions is used within the argument.	*"We think security is the most important thing, so we need to think about our security first."*
Not following	When the data and justifications are valid but not relevant to the conclusion.	*"We know many things about the uranium element, and therefore you can be sure that we will do all that we can to keep the nuclear plant safe."*	Slippery slope	An argument that predicts that a certain action will necessarily follow specific consequences without distinguishing any parts of the process.	*"Removing the nuclear plant will end up in the annihilation of the country."*	Equivalence	When two arguments are presented as logically equivalent (in quantity and quality) but as a matter of fact they are not.	*"Not removing the nuclear plant is intentionally hurting citizens' health and therefore no different from murder."*
Appeal to popularity	When a claim is justified because many people believe in its validity	*"Many of the citizens next to the plant think they are in great danger so therefore there is a great danger to their lives."*	Confusing correlation with causation	When two events that happen in close proximity are presented as necessarily causal	*"People in a city next to the nuclear plant die from cancer, surely because of the plant."*			

Irrelevance fallacies			**Presumption fallacies**			**Ambiguity fallacies**		
Red herring	When a rebuttal does not answer the issue, it was supposed to answer	*"You said that the citizens are fearful and insecure; well I tell you that the nuclear plant holds major importance for the security of the whole Country".*	Appeal to an authority	When a claim is strengthened by an authority that is not a reliable authority (criteria for approved authority can be found in Blair and Johnson's book, logical self-defense (2006)	*"Even the chief of staff says that no one around the nuclear plant is exposed to ionizing radiation."*			
			Strawman	Rephrasing the opposing argument in a way that will be much easier to refute.				

Interview analysis : The nature of the closed interview requires the focus on certain topics in advance. We coded the interview based on students' utterances relating to three aspects: Learning aspects, argumentation aspects and affective aspects. Learning aspects- students' utterances which related to the learning process during the prior lessons, preparation and the mock trial, mainly in comparison to more traditional teaching styles they were used to. Argumentation aspects- Students' utterances which related to the level of argumentation, norms of discourse and construction of knowledge through argumentation. Affective Aspects- Students utterances which related to motivation, emotions and self-efficacy.

V. RESULTS

We introduce the results according to the order of the research questions.

Research question 1- To what extent the learning environment supported argumentation?

The mock trial setting facilitated a productive and diverse argumentative environment, as evidenced by the 67 arguments made in each class. This demonstrates the success of creating a comfortable atmosphere where students felt free to express themselves. The pre-trial lessons that focused on acquiring content knowledge through historical events, were perceived by the students as an essential preparation for the mock-trial as demonstrated in the next quotes.

D (Y 2 Class):" I liked the lessons that talked about Thompson and Rutherford experiments. Because in junior high I learned about the atom, but no one had told me how they concluded things.
They just told me there are neutrons, protons and electrons. But with the explanation of the experiments I understood how they figured out the particles."

S (K Class, jury): *"[the lessons] helped me examine the arguments, to decide which of them was most reliable."*
Another prominent aspect students pointed out about the pre-trial lessons is the focus on ethical issues in science throughout the intervention.

L (K Class): "usually when we talk about science we say they discovered this and that, and in this activity, we suddenly discussed how science affects our lives, sometime for good and sometimes for bad."

Students' interviews indicate that the prior lessons helped to perceive science as embedded within society, in a live context they are familiar with, which we think prepared the ground for a complex and intense SSI activity such as the mock trial. Specifically regarding to argumentation, we observed that the argumentative environment had affected students' awareness and ability to reflect on their own arguments as well as their peers as can be concluded from the next quotes:

D (class Y2, jury): *" The trial helped me decide whether the arguments are scientific or not because the lawyers tried all kinds of slick arguments."*
M (class Y2, prosecution): *"The trial helped me listen to others' opinions."*

L (class K, jury): *"...During the trial, I felt when the arguments were not good, or when someone contradicted himself, or when he wasn't sure of what he was saying. On the other hand, there were arguments in which someone was consistent and stood up for what he said, and then I could say it was a good argument. I also tried to have no feelings involved in my decision, which was hard."*

B (class K, lawyer defense): *"We [the defense] used emotional arguments that were meant to affect them [the jury]. I know that on my team, the social aspect dominated. If we had had a few more days, then we could have used scientific arguments as well."*
N (K class):"I was agitated that the defense always clanged to the security argument"

Five interviewees in class Y2 indicated how the counter side's arguments affected them. Only one student said the trial did not affect his ability to judge arguments in general. All interviewees indicated their improvement in judging arguments during the mock trial.

Research question 2- What was the quality of the students' arguments?

To Figure 1 and 2 presents the distribution of students arguments throughout the mock trial based on the analysis which included the categorization of each argument.

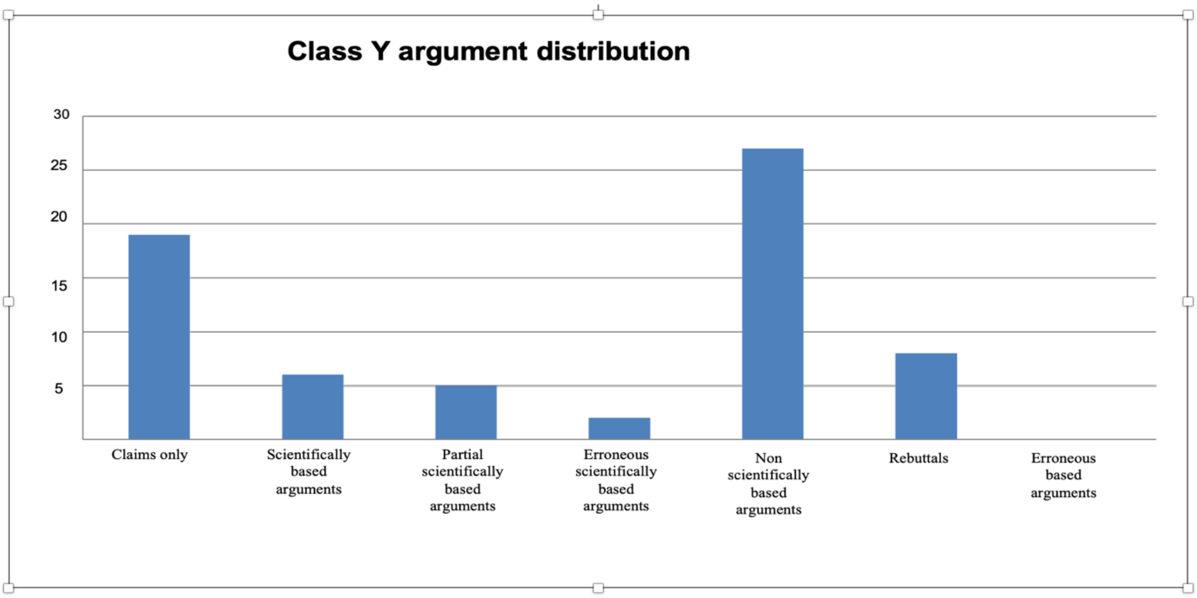

Fig. 1 *Argument distribution in class Y2 (N of students = 30)*

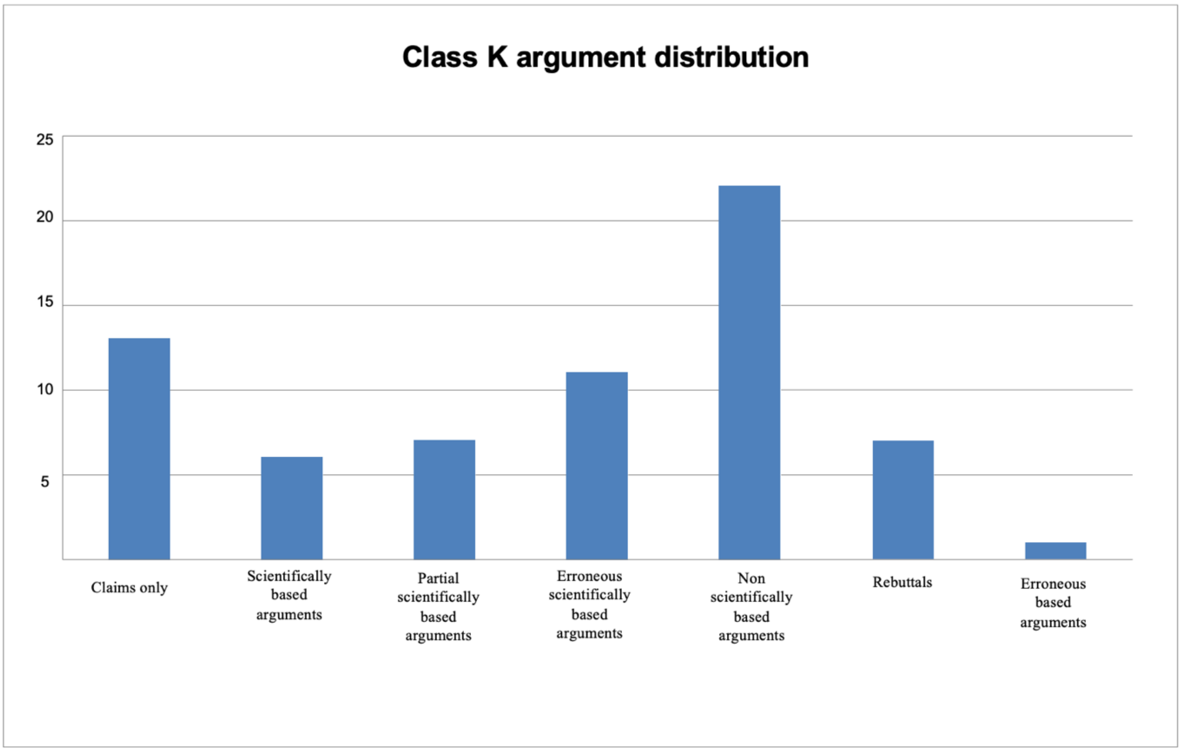

Fig.2 *Argument distribution in class K (N of students = 16)*

The results showed that the number of arguments in each class was equal, with 67 arguments in Y2 and 67 in K. Figures 1 and 2 display the distribution of argument types, which were found to have a similar pattern in both

classes. However, the number of unsupported claims differed slightly, with 19 in Y2 and 13 in K. The number of based arguments and rebuttals combined was 33 in Y2 and 28 in K. Despite being based on a sociocentric dilemma, the number of scientifically based arguments was relatively low, with only 6 per class. A spontaneous initiative of the students to bring laptops with them impacted the students' ability to formulate rebuttals, as one student noted how access to the web enabled them to construct rebuttals.
R (class Y2, witness): *"When someone opposed my opinion, I used the computer to search for information that could contradict or oppose him back. In this way, I was able to understand the material much better."* During the trial, it was clear that the students realized that convincing the jury depends on the quality of their arguments; and yet, they did not manage to raise enough arguments based on scientific data. It seems that the students had difficulty translating their knowledge on the atomic structure and nuclear energy into practice during the trial.

Fallacious arguments : Although most of the arguments were based on the minimal requirements for an argument by Toulmin's model—claim + data—many were discovered to be fallacious. We categorized the fallacies into irrelevance, presumption, and ambiguity fallacies (see section 4) (Govier, 2010; Walton, 1987). Table 2 indicates the fallacy types and their distribution.

Table 2 *-Frequency of fallacious arguments in class Y2*

Irrelevance		**Presumption**		**Ambiguity**	
Fallacy type	Number of fallacies	Fallacy type	Number of fallacies	Fallacy type	Number of fallacies
Relies on ignorance	10	Begging the question	15	Ambiguity	2
Internal contradiction	5	Hasty generalization	1	Equivalence	1
Red herring	3	Cause and effect	1	-	-
Not following	3	Slippery slope	4	-	-
Popularity	1	Appeal to an authority	4	-	-
Appeal to ignorance	1	Circular	1	-	-
Dismissing the argument	1	Bad analogy	1	-	-

Appeal to terror	1	False dilemma	1	-	-
		Statistics of small numbers	1	-	-

Table 3 *Frequency of fallacious arguments in class K*

Irrelevance		Presumption		Ambiguity	
Fallacy type	Number of fallacies	Fallacy type	Number of fallacies	Fallacy type	Number of fallacies
Relies on ignorance	14	Begging the question	6	Ambiguity	1
Internal contradiction	-	Hasty generalization	1	Equivalence	2
Red herring	1	Cause and effect	3	-	-
Not following	5	Slippery slope	3	-	-
Popularity	3	Appeal to an authority	3	-	-
Appeal to ignorance	-	Circular	1	-	-
Dismissing the argument	2	Bad analogy	1	-	-
Ad hominem	1	False dilemma	1	-	-
Appeal to pity	3	Statistics of small numbers	1	-	-
	-	Strawman	2	-	-
	-	Future assumption	1	-	-
	-	Selective observation	3	-	-
		No true Scot's man	1		
Sum	29	Sum	27	Sum	3

Various types of fallacies were observed, with a majority of fallacies of irrelevance and presumption. A high frequency of fallacies was observed in both classes, regardless of the argument level based on Toulmin's model. Some arguments lacked a solid basis and were merely superficial claims, thus could not be considered fallacious. In Class Y2 , the "begging the question" fallacy was the most prominent, appearing 15 times in different arguments. This fallacy occurs when the premise of an argument assumes the conclusion to be true, rather than providing support for it. For example, the statement "I am sure best efforts are being made to prevent a disaster…so we need to keep the reactor because it is safe" is a classic example of a circular argument, as the conclusion (the reactor is safe) is assumed in the premise (best efforts are being made to prevent a disaster).

Another prominent fallacy type was "relies on ignorance", which appeared ten times in different arguments. In this case, lack of evidence is used to support a conclusion. For example: *"There is no known or documented precedent for a leak or any malfunction of the reactor. Therefore, the reactor is safe to citizens nearby."* In this example the student argues that the fact there is no public documentation of reactor malfunction means that the

reactor is safe. In class K, the "relies on ignorance" fallacy was the most salient and frequent, appearing 14 times during the trial while other fallacies were equally distributed. As we predicted, most of the none- based arguments contained fallacies, yet surprisingly evidence-based arguments were found to be equally fallacious. Moreover, scientifically based arguments and partially scientifically based arguments were also found to consist equal amount of fallacies. As expected, except for one rebuttal none were fallacious, as rebuttals tend to reveal the fallacious logic of the argument. As already noted, a method for analyzing argument fallacies was chosen because TAP categories were insufficient to analyze the quality of students' arguments in the context of free speech. Here are some quotes from scientifically based and non-scientifically based arguments that contained informal fallacies. The quotations are taken from both classes' transcripts:
*A (*class Y2, lawyer): *"Another important thing is that many studies show that there is no danger living in proximity to a nuclear reactor. They have shown a low percentage of population morbidity in those places. Because the people in those places were financially well-off, they could afford to pay for private treatment."*

(**Internal contradiction**)
*D (*class Y2, witness): *"As you can see, this is the structure of the atom; it has protons that have a positive charge…this is the chain reaction, we take the ^{235}U isotope after the process of uranium enrichment that has...now this process was done in a controlled and slow manner, so we don't let anything happen."* (**Not following**, Y2 class)

A notable finding was that the majority of fallacious arguments were presented by students on the defense team, including lawyers and witnesses, in both classes. This may suggest that being on the defense side encourages students to be more argumentative and to adopt a more emotional approach. In Class Y2, most of the jury members based their decision on fallacies such as "slippery slope," "begging the question," and "appeal to terror." None of the juror's explanations were based on scientific evidence, despite having taken notes and summarizing the arguments from both sides. However, some of the jurors did critique the arguments presented by both sides. The following quotes are taken from the jury discussion in Class Y2:
"We can't take the risk that we won't have something to protect ourselves with; we will be attacked and won't be able to do anything." (**Slippery slope**)
"I also agree with the defense, because we can't stay without any weapon, I am sure the best efforts are being made to prevent disasters such as in Japan. The arsenal we possess now provides no comfort because as time goes by, new bombs will become available, so these bombs won't be sufficient." (**Internal contradiction,**

Slippery slope, Appeals to authority)
Class K had only four jurors, but their remarks during the trial were more thorough and deeper. Similarly to class Y2, two jurors based their arguments on the "slippery slope" and circular "begging the question" arguments based on the following logic: we need the reactor to maintain our security as a state because without it we are not safe. However, two students displayed deep critical thinking by attacking both sides' arguments with coherent explanations. Here are some examples.
R (Class K, Jury):"No one told us about the magnitude of a leak, how bad it will be; the defense just said that people would be evacuated to a 60 km distance, but is this a fact that we have such a security distance in our country?"
E (Class K, Jury):"I believe the reactor should be removed to a certain place and not be banished, so there won't be a threat to citizens, because I, as a citizen of Dimona, wouldn't be happy to live next to a reactor where radiation threatens me."
"I was disturbed by the defense always using the security argument…"

The main findings can be summarized as follows: the mock trial activity provided a rich and appropriate setting for argumentation, as evidenced by the total number of arguments presented during the intervention. The quantity of scientifically based arguments relying on scientific data and rationales was limited. The argumentative context impacted students' ability to critically evaluate and reflect on arguments made by others. A considerable number of arguments were flawed by informal fallacies, primarily of irrelevance and presumption.

VI. DISCUSSION

The mock trial activity proved to be an engaging and lively debate among the students. This was not only due to the sheer number and variety of arguments presented, but also to the students' enthusiastic participation, which was evident in their tone, body language, and the effort they put into winning. This sentiment was echoed by one of the interviewees, who stated, "The trial was really fun!" The distribution of argument types suggest that the students understood the need to ground their arguments in data and justify their claims. In particular, given the literature reports on the difficulty of students and adults to produce rebuttals in different argumentative settings (Erduran, 2007; Kolst⊘, 2006; Kuhn, 1991; Means & Voss, 1996; Sadler & Donnelly, 2006) the number of rebuttals made by the students is encouraging pointing out to students engagement in a cognitive process of reflection and synthesis of new arguments. The presence of high number of non-evidence-based arguments can be attributed to the tendency to present a claim or conclusion as a fact (relating to the "begging the question" fallacy) which can have several reasons. Firstly, in the purposely designed argumentative atmosphere in which students had almost complete freedom of speech, they did not feel accountable for their statements. Implementing an activity that requires students to write their arguments and submit them before the trial, might have reduce the number of arguments suffering from this fallacy. Secondly, we suggest that the relatively high number of non-evidence-based arguments is linked to the small number of evidence-based scientific arguments. The relatively infrequent reference to scientific concepts indicates that students had a challenge transferring prior knowledge covered in the lessons prior to the trial in the context of a SSI. This finding corresponds with literature reporting of the difficulty of transfer, applying content in other context in which it has been learned (Barnett & Ceci, 2002; Georghiades, 2000; Gilbert, Bulte, & Pilot, 2011; Perkins & Salomon, 1988; Von Aufschnaiter, et. al; Yang, 2004). In particular it corresponds with literature describing the challenges students face in producing sound arguments in a SSI context (Acar, Turkmen, & Roychoudhury, 2010; Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Sadler & Donnelly, 2006; Simonneaux, 2008). Another reason could be cultural as students might have imitated an often superficial and demagogic discourse prevalent in the media that lacks scientific terminology (Brumfiel, 2009). Perhaps a longer preparation time could have increased the number of scientifically based arguments as one of the students argued: "*We [the students] did not use scientific arguments due to lack of preparation time.*"

Finally, in this study we did not conduct an explicit introduction to argumentation that would include topics like argument structure and avoiding informal fallacies for two reasons; time constrains, and concern of further complicating the research. The case of Class Y2 highlights the significance of teaching argumentation as a fundamental part of education. Despite both the prosecution and the defense presenting compelling arguments, many of the students serving as jury members made their decision based on populist reasoning. This underscores the need to equip students with the skills to evaluate the quality of arguments and provide scaffolds that support the process of decision making (Driver et al., 2000; Shwartz, Ben-Zvi, & Hofstein, 2006). While some of the students in Class Y2 attempted to critically analyze the arguments presented, they ultimately aligned with the majority's opinion. In contrast, two students from Class K were able to effectively examine and challenge populist and flawed scientific arguments, demonstrating the benefits of argumentative activities for fostering analytical skills.

Many of the arguments raised in the trial were fallacious in both classes. The diversity of the fallacies suggests students' wide range of logic failures and the extent of the work needed to improve these habits of mind in the context of SSI. As other researchers have indicated we also argue that despite the great advantages of TAP, it is not enough of an indicator for argumentation analysis in a live discussion (Blair & Johnson, 2006; Nielsen, 2013). We found that although students may use data, justifications, and even back up their arguments, those measures are not sufficient to evaluate the argument's merit according to the framework of informal reasoning.

We showed that the use of informal fallacy analysis serves as complimentary tool for assessing students' arguments. Although informal fallacies were suggested as an effective assessment tool years ago (Weinstock et al., 2006; Zeidler et al., 1992), and were effectively taught in teachers professional development courses (Ikuenobe, 2001; Topcu, Sadler, & Yilmaz-Tuzun, 2010; Zohar, 2007) there still needs to be more research to be on the applicability of informal fallacies in science education, with a focus on SSI context. We See our contribution in this work in describing an analysis which is based on a concise list of fallacies, which can be easily used by others to assess arguments, especially in the context of SSI and live discussion over controversial issues.

Most of the fallacies in both cases were associated with presumption or irrelevance types; the most prominent were "begging the question" and "relies on ignorance." The first has a logical error; it is a specific case of the fallacy of a circular argument. Students who used this fallacy based their argument on a questionable premise as a given truth, this included the rephrasing of the premise as a conclusion. We think that this fallacy was common due to the short time preparation that was dedicated for the trial, which successively prompted the students to invent data or give partially falsified data. We think it led to the false logic that if one does not know the existence of A, then A must exist or on the other hand, must not exist. An example of this logic is apparent in class K, in which most of the arguments that relied on ignorance were based on incorrect scientific data. An additional cause for the fallacious reasoning could be due to a cultural factor; which means that in this sort of intellectual competition, the students believed that the end justified the means, and inventing data or falsifying it is legitimate in this very new constellation they first got to experience. Indeed, the results suggest that students acknowledged that supporting arguments with scientific data strengthens their arguments and increase the potential to convince other (Kolst⊘, 2006) as scientific terminology was commonly used during the trial, though sometimes in a misleading manner as one of the interviewees noticed: *"People made up things (scientific data) to convince and charm the jury."*The students in both classes have put a tremendous effort to improve their arguments during the trial. The fact that students spontaneously used the web to look up for data, to either back up their arguments or contradict the other side's arguments, is an indicator of their high level of engagement, and serves as further evidence in which computerized environments can support high-level cognitive skills and knowledge-construction processes (Clark et al., 2007; Schwarz & De Groot, 2007). This example shows that even simple technological tools integrated in learning environments such as the mock trial could result in higher quality of arguments.

The interviews proved beyond any doubt that all the students found the mock trial activity to be a positive and enjoyable experience. Some of them mentioned that although they had a great time, learning that way made them nervous because this was not part of their curricular and matriculation exams. Researchers have shown how students' motivation to learn science has decreased over the years (Vedder-Weiss & Fortus, 2012). Moreover, the negative psychological effects of external matriculation exams in Israel and in other countries on students' motivation to learn science has been described and it was suggested to reduce standardized testing of such kind (Tamir, 2011; Zakaria & Nordin, 2008). We believe that implementing intervention such as the one described in this paper can have positive effects on students' motivation to learn science. In conclusion, our study provides evidence that a mock trial is a highly effective learning environment that fosters student engagement in argumentation. This is especially relevant in a world marked by growing polarization between different groups (Dunlap, McCright, & Yarosh, 2016; Mason, 2015) as it offers an important opportunity to cultivate skills in respectful conflict resolution (Van Driel, Darmody, & Kerzil, 2016). Our research also supports the notion that argumentation skills are not simply acquired through aging, and that even high-achieving STEM students are vulnerable to fallacious reasoning (Kahneman, 2011; Mercier & Sperber, 2011; Tindale, 2007). Our findings reveal a discrepancy in argument quality when assessed through TAP and informal fallacies, highlighting the critical role that context and framework play in argument evaluation. By demonstrating the value of using informal fallacies as a means of assessing arguments within the context of SSI, our results have significant implications for both research and teaching.

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