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Academic Debate as a Pedagogical Strategy in STEM Higher Education: experiences in the University of Palermo

Il dibattito accademico come strategia pedagogica nell'istruzione universitaria delle STEM: esperienze presso l'Università di Palermo

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Abstract
The use of structured academic debate is gaining momentum in Italian higher education as a student-centered, active learning methodology. At the University of Palermo (UNIPA), the Guided University Debate (GUD), an adaptation of the World Schools Debate format, has been implemented in various disciplines, including STEM fields such as Chemistry, Biotechnology, and Chemical Engineering. This article presents and analyzes the pedagogical experience of integrating debate within the curricula of these disciplines, focusing on two specific case studies: the History of Chemistry course and the training seminars for newly appointed faculty. The experiences demonstrated that academic debate could enhance critical thinking, collaborative learning, oral communication, and ethical reasoning, competencies aligned with the Tuning Educational Structures in Europe. Students reported increased engagement, better understanding of complex content, and improved teamwork and argumentation skills. Despite logistical challenges such as time constraints and initial resistance from both students and faculty, the results underscore the potential of debate to enrich scientific education. We discuss the implications of these findings within the broader context of educational innovation in STEM, comparing them with similar international experiences. Ultimately, this paper advocates for a wider adoption of debate methodologies in higher education as part of a holistic approach to scientific literacy and professional competence.

Keywords: Academic debate; Active learning; STEM education; Higher education pedagogy.

Riassunto
L'uso del dibattito accademico strutturato sta acquisendo sempre maggiore rilevanza nell'istruzione universitaria italiana come metodologia di apprendimento attivo e centrato sullo studente. All'Università di Palermo (UNIPA), il Guided University Debate (GUD), adattamento del formato del World Schools Debate, è stato applicato in diverse discipline, incluse aree STEM come Chimica, Biotecnologie e Ingegneria Chimica. Questo articolo presenta e analizza l'esperienza pedagogica di integrazione del dibattito all'interno dei curricula di tali discipline, concentrandosi su due casi specifici: il corso di Storia della Chimica e i seminari di formazione rivolti ai docenti di nuova nomina. Le esperienze hanno dimostrato che il dibattito accademico può potenziare il pensiero critico, l'apprendimento collaborativo, la comunicazione orale e il ragionamento etico, competenze in linea con il quadro del Tuning Educational Structures in Europe. Gli studenti hanno riportato un maggiore coinvolgimento, una comprensione più profonda di contenuti complessi e un miglioramento nelle capacità di lavoro di gruppo e di argomentazione. Nonostante le difficoltà organizzative, come la limitata disponibilità di tempo e una iniziale resistenza da parte di studenti e docenti, i risultati evidenziano il potenziale del dibattito come strumento per arricchire la formazione scientifica. L'articolo discute le implicazioni di tali risultati nel più ampio contesto dell'innovazione didattica nelle discipline STEM, confrontandoli con esperienze analoghe a livello internazionale. In conclusione, si sostiene la necessità di una più ampia adozione delle metodologie basate sul dibattito nell'istruzione superiore, come parte di un approccio olistico alla scientific literacy e allo sviluppo delle competenze professionali.

Parole chiavi: Dibattito accademico; Apprendimento attivo; Educazione STEM; Pedagogia dell'istruzione superiore.

1. Introduction

In recent years, university education in science, technology, engineering and mathematics (STEM) has been increasingly challenged to combine disciplinary rigor with the development of transversal competences. Communication skills, critical thinking, the capacity to argue based on evidence, and collaborative attitudes are now widely recognized as core components of scientific literacy, especially in higher education settings (Freeman et al., 2014; Prince, 2004). This article presents and analyzes the pedagogical experience at the University of Palermo of integrating debate within the curricula of these disciplines. Far from being limited to humanities or political science, the methodology of debate, particularly in its "Oxford-style" (Snider & Schnurer, 2006) or "World Schools" (Quinn, 2008) formats, has proven effective in fostering deep conceptual understanding, stimulating engagement, and promoting metacognitive reflection, even within content-rich scientific disciplines such as chemistry, biotechnology and engineering (Hendratmoko et al., 2024). Rather than designing a formal research study, we intend to share here a reflective account of our experiences during which debate activities have been integrated into undergraduate STEM courses. These experiences have been shaped by a pragmatic approach to innovation: exploring how a method rooted in rhetorical and dialogical tradition can be adapted to the epistemological frameworks of STEM subjects, and to the expectations of students who often see these disciplines as purely technical or procedural. The implementation of debate has allowed us to observe how students respond to the challenge of articulating arguments in support of or against controversial scientific statements, ranging from the interpretation of historical models of the atom, to ethical implications of biotechnology, or the societal roles of chemistry. Students were not only encouraged to explore and communicate scientific content, but also to reflect critically on its implications, sources, and underlying assumptions. This article adopts a multiple case study perspective, presenting and comparing four debate implementations across different STEM contexts. Each case is described using a common set of descriptors, context, participants, format, and outcomes, to facilitate cross-case reflection rather than formal statistical comparison. It aims to describe these educational practices, contextualize them within international literature on active learning in STEM, and offer insights and considerations for colleagues who may wish to experiment with debate as a learning strategy in their own teaching. In doing so, we hope to contribute to a broader conversation about disciplinary and interdisciplinary approaches to university teaching, and to support the shift from transmissive to participatory models of instruction in science education.

2. Debate as a Pedagogical Method in STEM Education

The educational debate is a structured dialogical practice in which two opposing teams present, defend, and challenge positions on a controversial statement. While traditionally associated with political science or law, the debate methodology has gained increasing recognition as a powerful pedagogical tool in science education. Grounded in constructivist and socio-cognitive theories of learning, debate fosters active engagement, argument-based reasoning, and critical reflection, all key competences in STEM fields. From a pedagogical standpoint, debate operationalizes core principles of constructivist learning (Kolb, 1984; Vygotsky, 1978) and aligns with the framework of argumentation in science education (Driver et al., 2000; Erduran & Jiménez-Aleixandre, 2007; Osborne et al., 2004). It promotes dialogic knowledge construction, scaffolds metacognitive reflection, and situates learning within authentic reasoning practices of the discipline.

A typical debate cycle includes the formulation of a motion, the assignment of roles (affirmative, negative, judges), and the preparation and public presentation of arguments based on evidence. In its most widely used versions, such as the Oxford-Style Debate or the World Schools Debate (WSD) format, students engage in activities that require them to research, evaluate, and synthesize scientific information, often from conflicting perspectives. This structure creates an authentic context for learning by arguing, where the focus is not only on mastering content but also on interpreting data, building persuasive reasoning, and anticipating counterarguments. Several studies have documented the educational value of debate in STEM settings. Boucaud et al. implemented Oxford-style debates in an undergraduate microbiology course (Boucaud et al., 2013), finding that students retained knowledge derived from debates significantly better than that presented in lectures. Notably, students with lower performance in lecture-based assessments scored equally well on debate-related questions, suggesting that this approach can serve as a levelling strategy and support diverse learners. Moreover, participants reported increased confidence in using scientific databases and in analyzing primary literature—skills fundamental to scientific inquiry. A similar perspective is offered by Alfarah et al., who introduced structured debates in pharmacy education (Alfarah et al., 2023), aiming to enhance both subject mastery and communication abilities. The results indicated that debate activities cultivated students' ability to construct logical arguments, articulate uncertainty, and handle complex information under time constraints, conditions similar to real-world professional practice. In a broader review, Hendratmoko et al. analyzed the integration of inquiry and debate in science learning (Hendratmoko et al., 2024). Their systematic mapping of the literature showed that, although these approaches are often treated separately, their combination has a strong potential to enhance students' scientific argumentation. This includes the ability to articulate claims supported by evidence, engage with alternative views, and reflect on the epistemic status of scientific knowledge. From a pedagogical point of view, the value of debate in STEM education lies in its capacity to activate higher-order cognitive processes, as described in Bloom's taxonomy, analysis, synthesis, and evaluation, within a socially interactive environment. The method promotes cognitive restructuring (learning through contradiction), metacognitive awareness (reflecting on reasoning strategies), and collaborative learning (constructing knowledge in teams). Moreover, it aligns with international frameworks for transversal competences in higher education, such as those defined by the Tuning Project, including problem-solving, communication, and ethical awareness. While academic debate is well-established in Anglo-Saxon universities, with institutional support through dedicated courses, debate clubs, and scholarships (Mazzei, 2022; McDonald, 2000), its presence in Italian academia is relatively recent and underutilized, especially in STEM context. Common barriers include perceived incompatibility with scientific rigor, time constraints, and lack of familiarity among instructors. Nevertheless, growing empirical evidence and practical experiences, such as those described in this article, show that, when adapted with disciplinary sensitivity, debate can enrich the STEM curriculum and contribute to a more holistic and participatory model of science education.

2.1 Designing Effective Disciplinary Motions in STEM Debate

While the general pedagogical value of debate in STEM education lies in its ability to foster evidence-based reasoning and collaborative learning, its actual impact depends on how the motion is conceived. In disciplinary contexts, the formulation of the motion determines whether the discussion remains superficial or truly activates conceptual understanding and scientific argumentation.

A disciplinary motion must simultaneously activate core scientific knowledge and the reasoning practices characteristic of the field, interpreting data, evaluating evidence, and negotiating uncertainty. The wording of the motion shapes not only what students discuss, but also how they reason scientifically.

An effective strategy may be to follow a three-step process:

1. Identify a disciplinary tension. Choose a topic where legitimate disagreement or conceptual contrast exists between competing models, methodological perspectives, or educational rationales.
2. Reframe the tension as a debatable claim. Phrase it as a concise statement that invites a clear affirmative or negative position while requiring evidence-based justification.
3. Anticipate the epistemic operations. Plan which cognitive and argumentative moves the debate should elicit: applying experimental evidence, comparing models, or evaluating ethical and societal implications.

The motion "A History of Chemistry course has no place in a science degree" illustrates this process. It originated from a genuine pedagogical question about the role of historical and epistemological reflection in scientific curricula. By formulating it as a binary claim, students were compelled to confront the value and limitations of historical thinking in chemistry.

– The Pro side argued that science advances by superseding outdated models and that curricular time should focus on current theories, methods, and laboratory work. They emphasized efficiency, specialization, and the pragmatic orientation of modern chemistry.
– The Con side maintained that understanding how chemical ideas evolve clarifies the logic of discovery, prevents misconceptions, and nurtures critical awareness of the scientific process. They drew on historical sources and on the human domain of Mahaffy's tetrahedron (Mahaffy, 2006), linking chemistry to culture, ethics, and communication.

In this way, the motion engaged all four domains of chemical knowledge, macroscopic, microscopic, symbolic, and humanistic, demonstrating how a single statement can catalyze both disciplinary and metadisciplinary reflection. Similar design logic guided other debates, such as "The Thomson atomic model is correct" or "A natural Christmas tree is more sustainable than an artificial one," which mobilized empirical evidence and quantitative reasoning while preserving the argumentative structure of scientific inquiry.

3. Experiences from the University of Palermo

The debate experiences presented in this article have been developed by a group of lecturers who share a common background: active participation in the *Mentori per la Didattica Project*, a peer-based faculty development initiative launched in 2013 at the University of Palermo (Scaccianoce et al., 2024). Entirely voluntary and interdisciplinary, the project fosters reflective practice and pedagogical innovation through mutual observation, dialogue among colleagues, and shared experimentation. One of the aims of the *Mentori Project* is to promote the use of specific teaching methodologies that can enhance the quality and effectiveness of university education. In this context, debate has emerged not as an externally introduced technique but as a collectively explored practice, tested in pilot courses and refined through peer discussion. The annual residential workshops and the informal cooperation among participants, particularly during the pandemic emergency, have supported the emergence of a shared culture of experimentation, where active learning and disciplinary reflection go hand in hand.

In parallel, debate has also been introduced in the faculty training programs coordinated by the TLC CIMDU, the University of Palermo's Teaching and Learning Centre for pedagogical innovation and enhancement. Among its various activities, the Centre organizes workshops and structured training courses for newly appointed faculty members. In these settings, debate is not only presented as a pedagogical strategy, but is experienced firsthand by the participants, who are guided through simulations and collective reflections. This immersive approach has enabled many instructors, including those in scientific disciplines, to appreciate the potential of debate in supporting critical thinking, fostering communication skills, and promoting deeper conceptual understanding.

3.1 Methodological note

The reflections presented in this article derive from four implementations of the Guided University Debate (2021–2025) carried out in chemistry, biotechnology, and chemical engineering courses, as well as in the debate-based seminars organized within the TLC-CIMDU faculty development program. Data were collected through classroom observations, analysis of students' preparatory materials (notes, slides, shared documents), and post-activity discussions and written reflections conducted with both students and instructors. These sources provided qualitative evidence on participation, argumentation strategies, and disciplinary engagement. The analysis combined descriptive accounts of how debates unfolded with interpretive reflection on observed patterns of reasoning, collaboration, and metacognitive awareness. The discussion of outcomes therefore integrates empirical observation with reflective interpretation, consistent with the exploratory and developmental nature of this study.

4. Debate in the bachelor's degree in chemistry

4.1 Course and context

The debate was implemented within the History of Chemistry course, offered in the first semester of the first year of the bachelor's degree in chemistry at the University of Palermo. The main objective was to make a historically and epistemologically oriented course more engaging for students who often expect a scientific curriculum to focus mainly on formulas, laboratory techniques, and problem solving. The activity aimed to help students understand how historical reflection contributes to the development of chemical knowledge and to the formation of professional and ethical awareness.

4.2 Participants

Between 2021 and 2024, about 150 students, took part in the debate-based seminars. Each session involved around 30 to 40 participants, ensuring small-group interaction and interdisciplinary exchange of perspectives. They were randomly divided into three groups: a Pro team, a Con team, and a jury composed of the remaining students. This structure ensured the participation of the entire class and allowed students to experience the debate from multiple perspectives, advocating, opposing, and evaluating arguments.

4.3 Format and duration

The debate followed the Guided University Debate (GUD) model, adapted to the disciplinary aims of the course. To maximize participation and promote multiple forms of engagement, the instructors introduced a modification to the traditional debate structure. Instead of organizing the class into just two opposing teams, they formed three distinct groups: a pro team, a con team, and a jury team. This tripartite configuration allowed every student in the course to be actively involved, either by defending a position, challenging opposing arguments, or evaluating the quality and coherence of the debate.

The motion proposed, "A History of Chemistry course has no place in a science degree", was deliberately provocative, inviting students to reflect on the relationship between scientific progress, historical awareness, and education. The preparation phase lasted about two weeks and combined individual study with group collaboration. The final debate took place in presence, lasted approximately one hour, and was moderated by the instructor, who ensured balanced participation and observance of the format. At the end of the activity, a collective debriefing session was conducted under the instructor's guidance. During this discussion, students and teacher jointly analysed the arguments presented, reflected on the quality and coherence of the evidence used, and identified the reasoning strategies that had proved most effective.

4.4 Preparation and support

The pro and con groups were supported by a coach each, a teacher who guided the team through the preparation process. The coach's role was not limited to content supervision but extended to methodological and relational support. Coaches helped students select and interpret sources, formulate coherent arguments, anticipate rebuttals, and organize internal collaboration. They also played a key role in managing the emotional dynamics of the activity, especially for students unfamiliar with public speaking or hesitant to take a clear stance in a disciplinary context.

The jury team evaluated the debating groups based on a set of clear and structured criteria, aimed at assessing both the quality of the arguments and the effectiveness of the communication. Particular attention was given to the variety of arguments proposed, the coordination of interventions within each team, the ability to respond to counterarguments, the clarity of exposition and the overall oratory skills demonstrated during the debate. These criteria provided a useful framework for guiding the jury's evaluations and helped students reflect on the key elements that contribute to constructing an effective and convincing scientific argument.

4.5 Main outcomes

The debate stimulated lively engagement and critical reflection. Students developed not only critical listening skills and content awareness, but also the ability to formulate reasoned judgments and give constructive feedback, competences rarely cultivated in traditional STEM courses.

The two teams presented well-structured and articulated positions, offering a rich panorama of arguments that reflected both disciplinary awareness and the ability to reason critically on broader educational and epistemological issues. The jury's feedback highlighted improved clarity of expression, better use of disciplinary language, and greater attention to the logical structure of arguments.

The debate experience proved particularly effective in stimulating motivation and participation. It helped students reconsider the role of historical and epistemological reflection in scientific education and revealed the relevance of debate as a tool to explore the cultural, conceptual, and ethical dimensions of chemistry. For many participants, it was a first opportunity to engage publicly with complex ideas, defend a position with evidence and reflect on the nature of science not only as a body of knowledge, but as a human and evolving enterprise.

5. Debate in Faculty Training

5.1 Course and context

Debate activities were also implemented within the faculty development programme coordinated by the Teaching and Learning Centre (TLC–CIMDU) at the University of Palermo. These seminars are part of the pedagogical training offered to newly appointed faculty members and aim to promote awareness and experimentation with active-learning methodologies. Within this context, debate was adopted not only as a topic of discussion but also as an experiential activity, allowing participants to explore directly the dynamics of collaborative and dialogic learning.

5.2 Participants

Between 2022 and 2025, about 150 faculty members from different disciplinary areas, including science, engineering, humanities, and social sciences, took part in the debate-based seminars. Each session involved around 25 to 30 participants, ensuring small-group interaction and interdisciplinary exchange of perspectives.

5.3 Format and duration

Each seminar lasted approximately three hours and combined theoretical framing, guided practice, and collective reflection. Participants were divided into two debating teams (Pro and Con) and a jury, following the World Schools Debate structure adapted to the university context. The motions addressed educational topics relevant to higher education, for instance, "Traditional lectures remain essential for university teaching" or "Assessment should prioritise learning processes over outcomes." After an introductory briefing, participants prepared their arguments collaboratively for about thirty minutes, followed by a 45-minute debate and a final debriefing discussion.

5.4 Preparation and support

The facilitators introduced the pedagogical foundations of debate and provided guidance on team organisation, communication strategies, and use of evidence. During preparation, participants worked together to develop arguments, share disciplinary insights, and anticipate counterpoints. The process was designed to model the same active-learning strategies that faculty might later implement with their students. Observation of the sessions and post-activity discussions revealed that taking part both as debaters and as jurors helped participants to appreciate the multiple cognitive and relational dimensions of classroom dialogue.

5.5 Main outcomes

The integration of debate into faculty training proved effective in fostering reflection on teaching practices and in promoting a more student-centred approach. Participants reported that the experience enhanced their understanding of active learning and increased their confidence in applying dialogic and collaborative methods. The collective reflection that followed each debate encouraged awareness of the balance between content delivery and student participation, and many faculty members expressed an intention to introduce debate or similar structured discussions into their own courses. Observations indicated that the activity stimulated metacognitive reflection on the role of communication, reasoning, and evidence in university teaching, contributing to the formation of a growing community of practice dedicated to innovative pedagogy.

6. Debate in the bachelor's degree in biotechnology

6.1 Course and context

The debate was implemented within the General Chemistry course of the first year of the bachelor's degree in biotechnology at the University of Palermo. The initiative was designed to enhance student engagement in a subject often perceived as distant from the biological and biomedical focus of the program. By introducing debate, the instructor aimed to promote active participation, strengthen conceptual understanding, and encourage reflection on the epistemological nature of scientific models.

6.2 Participants

The debate involved approximately 60 students, divided into three teams: a pro team of 10 students, a con team of 10 students and a jury team composed of the remaining students. This structure was intentionally designed to ensure the active participation of all, whether by defending a position, challenging opposing arguments or evaluating the quality of the debate itself

6.3 Format and duration

The debate followed the Guided University Debate (GUD) format. The motion proposed, "The Thomson atomic model is correct", was intentionally paradoxical, inviting students to examine how scientific models evolve considering new evidence. Preparation took place over two weeks through small-group collaboration, followed by a live debate session of about one hour. The instructor acted as moderator, ensuring balanced participation and adherence to the debate format. The activity concluded with a collective debriefing facilitated by the instructors, who guided students to connect the arguments of both sides with key epistemological concepts such as falsifiability, model revision, and the role of experimental evidence in shaping scientific theories.

6.4 Preparation and support

The preparation phase took place remotely, with students working in small groups to gather information, construct arguments and organize their strategies, assisted by tutors when needed. This modality allowed students to collaborate flexibly while developing autonomy in managing tasks and deadlines. The debate itself was conducted in presence, under the guidance of the course instructor, who facilitated the discussion, ensured fairness in the procedure and helped the jury team in applying the evaluation rubric.

6.5 Main outcomes

The debate stimulated active engagement and allowed students to reflect on the provisional character of scientific knowledge, on how models are constructed to interpret experimental evidence, and on the reasons why some theories are eventually abandoned. Through this lens, the debate encouraged students to explore not only the specific content of atomic theory but also the broader epistemological processes that characterize the evolution of science. The Pro team highlighted the internal coherence of the Thomson model within its historical context, whereas the Con team focused on the decisive experimental evidence that led to its rejection. Both groups demonstrated an ability to reason with evidence rather than opinion and to connect theoretical knowledge with the processes of model construction and revision. The jury's feedback and post-activity reflections revealed an appreciation for the interactive and reflective character of the exercise, which transformed a traditionally theoretical topic into an opportunity for inquiry and discussion.

7. Debate in the master's degree in Chemical Engineering

7.1 Course and context

The debate activity was integrated into a first-semester course of the master's degree in chemical engineering at the University of Palermo. The initiative sought to encourage students to address complex sustainability issues through evidence-based reasoning and interdisciplinary reflection. Within an advanced engineering curriculum, the debate served as a means to connect quantitative analysis with ethical and environmental considerations, thereby enriching students' understanding of the societal relevance of their discipline.

7.2 Participants

Thirty students participated in the activity, divided into two teams of fifteen members each: one supporting and one opposing the motion. This structure was selected to allow extended participation and to stimulate collaboration within relatively small groups, facilitating in-depth preparation and discussion.

7.3 Format and duration

The debate followed the Guided University Debate (GUD) model. The motion proposed, "A natural Christmas tree is better for the environment than an artificial one", although apparently peripheral to the core curriculum of chemical engineering, was deliberately chosen for its potential to stimulate discussion on life cycle thinking, environmental impact assessment and sustainability criteria. It required students to go beyond intuitive reasoning and to ground their arguments in quantitative data and evidence from the scientific literature.

Preparation took place over two weeks, combining autonomous research and guided supervision. The final in-class debate lasted approximately seventy-five minutes and included three rounds of structured interventions per team, followed by a collective debriefing.

7.4 Preparation and support

The preparation phase took place remotely, with students working in groups to search for information, collect data from scientific studies and organize their arguments. During this phase, particular emphasis was placed on the use of Life Cycle Assessment (LCA) studies available in the literature. Students were guided in identifying relevant publications, analyzing methodologies and interpreting results in a critical manner. This process provided them with valuable experience in scientific literature research, data analysis and evidence-based argumentation.

7.5 Main outcomes

The students' arguments reflected the complexity of the topic. Both teams made extensive use of LCA studies to support their positions, but the debate itself highlighted how results from LCA analyses can vary considerably depending on assumptions, system boundaries and impact categories considered. This led to a broader reflection on the limitations and potential biases inherent in this widely used methodology.

Students reported a high level of satisfaction with the debate experience. In particular, they appreciated the opportunity to engage critically with real-world data and to confront the complexities and ambiguities often encountered in environmental impact assessments. The activity allowed them to develop greater awareness of the importance of methodological rigor in LCA studies and to recognize the need for critical evaluation when interpreting scientific results.

Feedback collected after the session confirmed that students found the debate format both stimulating and effective. They highlighted how the activity had strengthened their skills in critical reading of scientific literature, collaborative problem-solving and structured argumentation, all essential competences for future engineers operating in contexts where environmental and sustainability considerations are increasingly central.

Conclusions

The experiences described in this article confirm that the debate methodology can be fruitfully applied to STEM education at university level, even in contexts where dialogical and argumentative practices might initially appear distant from disciplinary traditions. Far from being an occasional or decorative activity, the debate has proven to be a valuable tool for fostering student engagement, critical thinking, and epistemological awareness, while also enhancing transversal competences that are increasingly required in scientific and professional environments.

Despite the different disciplinary contexts, chemistry, biotechnology and chemical engineering, the debate activities shared some significant outcomes. In all cases, students showed a clear increase in motivation and active participation, particularly in courses or topics often perceived as difficult or disconnected from their immediate academic interests. The opportunity to take an active role, to construct and defend arguments, and to engage with peers in structured and rule-based confrontation fostered a deeper commitment to learning processes.

The feedback gathered from students highlights the positive reception of these activities, perceived not only as engaging and stimulating but also as formative experiences that contribute to a deeper understanding of science, its methods and its social relevance.

The formulation of the motion plays a relevant role on the learning outcomes. When debates were based on authentic epistemic or methodological tensions, such as the interpretation of scientific models, the evaluation of experimental evidence, or the ethical and sustainability implications of technological choices, students engaged more deeply with disciplinary content. Well-constructed motions encouraged them to connect theoretical knowledge with reasoning practices, activating conceptual understanding across the macroscopic, microscopic, symbolic, and human domains of scientific literacy.

Across all contexts, participants showed a progressive shift from intuitive opinions to structured, evidence-based reasoning. Arguments increasingly referred to experimental data, quantitative analyses, and scientific literature, reflecting greater awareness of how evidence supports claims within a discipline. This evolution suggests that debate, when grounded in deliberate motion design, fosters argumentative literacy, the ability to construct, evaluate, and communicate claims according to disciplinary standards.

Overall, these findings highlight that the educational value of debate in STEM depends less on its format than on the thoughtful design of motions that align conceptual, methodological, and ethical dimensions of scientific reasoning.

Moreover, the debate encouraged students to develop competences not traditionally associated with STEM curricula, such as the ability to argue clearly and persuasively, to evaluate critically the reliability and relevance of sources, and to collaborate effectively within a team. Particularly meaningful was the reflection on the nature of scientific knowledge, its provisional character, and the mechanisms through which models and theories are constructed, revised and sometimes abandoned. These reflections were especially evident in the debates on the Thomson atomic model and on the comparative environmental impacts of natural and artificial Christmas trees, where students engaged critically with Life Cycle Assessment (LCA) studies, recognizing their potential but also their inherent limitations.

The involvement of student juries, where foreseen, further contributed to the development of evaluation skills and critical observation, encouraging meta-cognitive reflection on what constitutes a well-founded scientific argument.

In all the courses where a jury team was included, students were asked to apply a structured evaluation rubric addressing the clarity, coherence, and evidential support of each argument. The rubric was discussed collectively before the debate and used as the basis for the final debriefing. Acting as jurors encouraged participants to observe peers critically, to articulate criteria for what constitutes a valid scientific argument, and to justify their evaluations publicly. This evaluative perspective proved especially effective in promoting metacognitive reflection: students reported that judging others' reasoning helped them recognize strengths and weaknesses in their own argumentation and in the use of sources.

This experience suggests that the role of the jury could be further systematized, especially in contexts where the debate methodology is used repeatedly within a course. A more structured approach to jury work could strengthen students' awareness of evaluation criteria and deepen their understanding of argumentation strategies from a reflective, observer-based perspective. The division of the class into three distinct teams: pro, con and jury, appears particularly promising in this regard, offering a rotation of roles that supports engagement and the development of a wider range of competences.

Debate has proven to be a widely appreciated teaching method among young faculty members, who find it both engaging and relatively easy to implement in the classroom.

At the same time, some challenges emerged. Preparing students for a meaningful debate requires time, careful planning and appropriate support, especially in disciplines where argumentation is not usually part of the curriculum. Despite these hurdles, the seminar sparked a lasting impact, fostering a peer-led network of ambassadors committed to promoting debate and supporting its integration across disciplines.

The role of tutors or coaches proved helpful, not only for guiding content-related preparation but also for helping students manage organizational dynamics and emotional factors linked to public speaking and confrontation.

From a broader perspective, these experiences suggest that debate can be a powerful lever for renewing teaching practices in STEM, supporting a shift from transmissive models towards more participatory and reflective approaches. Moreover, debate contributes to the development of key competences identified at European level, such as critical thinking, communication and collaboration, and aligns with the objectives of interdisciplinary teaching and sustainability education.

Across all contexts, debate proved effective in fostering motivation, participation, and disciplinary reasoning, particularly in topics students initially perceived as abstract or distant. Common benefits included stronger teamwork, greater use of evidence, and improved confidence in scientific communication. Differences mainly concerned disciplinary focus and prior familiarity with argumentation: engineering debates required closer methodological guidance, whereas chemistry activities benefited from historical framing. Time constraints and initial hesitation toward public discussion remained the main challenges. Overall, the comparison suggests that the impact of debate depends on balancing autonomy and scaffolding and on tailoring motion design to each disciplinary culture, providing a basis for future refinement and wider implementation.

Looking ahead, it would be desirable to integrate debate activities more systematically into curricula, extending their use beyond isolated initiatives and connecting them to other active learning methodologies such as problem-based learning or inquiry-based approaches.

Building communities of practice among teachers interested in innovative teaching strategies could further support this process, fostering a culture of shared reflection, experimentation and continuous improvement.

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