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# The Impact of a Chemistry Competition on Students' Skills and Personal Attributes

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## ABSTRACT

This article examines the impact of a science competition (French Chemists' Tournament) on the engagement and performance of a graduate student team from the University of Montpellier as they  
10 compete against teams from some of the most prestigious French institutions. After outlining the French higher education system and the details of the tournament, we analyze the results of a questionnaire designed to assess participants' perceptions of their knowledge and skills, including communication, self-confidence, and motivation. Student interviews were also conducted.

## GRAPHICAL ABSTRACT



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## KEYWORDS

Graduate Education / Research, Collaborative / Cooperative Learning, Communication / Writing, Problem Solving / Decision Making, Undergraduate Research.

20 In many countries, two systems of higher education coexist: the more accessible universities and the more elitist “grandes écoles” or prestigious universities. These more accessible institutions can harbor deserving, hardworking and high-potential students who are important to identify and promote. Science competitions, such as chemistry tournaments, are effective tools for achieving these

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objectives. They help bring out the best university students, who may not be identified early on when  
25 entering university for various reasons (social, level of involvement, maturity/motivation) and help  
boost their careers.

The aim of this article is to examine whether students' participation in a prestigious chemistry  
tournament allows them to gain new knowledge, skills, communication abilities, self-confidence and  
motivation to the highest level within just a few months. In other words, can this participation elevate  
30 them to the level of students from the French elite "grandes écoles"? To address this, we begin by  
describing the current landscape of tournaments and competitions, followed by a brief overview of the  
French higher education system (for more details, see SI-1 of "the French higher education system"  
p.S1-S3), focusing on the schools and universities involved in the chemistry tournament. We then  
describe the tournament and its year-long preparation. Finally, we examine the students' results and  
35 their reflections on the experience, using a questionnaire we devised and interviews we conducted.

## STATE OF THE ART

Classroom competitions are a form of active learning, which has been shown to benefit both  
pedagogy and student outcomes.<sup>1</sup> Freeman *et al.*<sup>2</sup> conducted a meta-analysis of 158 studies published  
40 in around 50 science education journals and found that students' test scores increased by nearly half  
a grade point as a result of active learning. Additionally, students in traditional lecture-based classes  
were 1.5 times more likely to fail than their peers in classes that incorporated active learning.

In recent years, the educational community has reported positive results from implementing  
classroom competitions, including improved exam grades.<sup>3-5</sup> Like any active learning method used for  
45 assessment, competitions have both advantages and disadvantages.<sup>6</sup> They can create a "game-like"  
atmosphere, boosting students' interest, fostering group cohesion and motivating them to achieve  
higher performance.<sup>7</sup> However, if poorly designed, competitions can have negative effects, such as  
increased stress, tension between students and anxiety due to fear of poor grades or failure. In  
addition, students might invest excessive time and effort, neglecting their other coursework. Despite  
50 these concerns, a well-organized competition can be highly beneficial for students. The preparation  
and the competition itself should be relatively short to avoid excessive energy expenditure, and the

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rules and objectives should be clear, with outcomes that are beneficial to their curriculum. Students should receive appropriate rewards and, crucially, feel that they have a fair chance of winning or achieving a high mark.<sup>7</sup>

55        However, while the literature includes descriptions of competitions,<sup>8-11</sup> there is a lack of studies demonstrating their effectiveness. Shelley *et al.* have highlighted the need for more quantitative and statistical analyses to establish their benefits in science education.<sup>12</sup> Some authors have included feedback questionnaires in their description of these tournaments but more comprehensive studies are needed to validate their impact.<sup>13-16</sup>

60        Another consistent feature across most higher education systems is the presence of (highly) hierarchical institutions as evidenced by various national and international academic ranking systems. As a result, the best students are often early orientated toward the “best” institutions.

In particular, higher education in France can be pursued through short vocationally oriented programs (lasting two or three years), which enable direct entry into the job market, or through long  
65        courses (typically five to eight years) at universities and specialized institutions named “grandes écoles”. Higher education students who are destined for long studies enter either the university or a “grande école” such as the Ecoles Normales Supérieures (ENS Paris Saclay, ENS Lyon, ENS Ulm), Ecole Polytechnique, Mines, Ponts, Centrale Supélec, Ecole Supérieure de Physique et de Chimie Industrielles de la ville de Paris (ESPCI-Université PSL), Chimie Paris Tech-PSL comparable to the Ivy  
70        League in the USA, the C9 League in China, the Golden Triangle in the UK and the Imperial Universities Japan.<sup>17</sup>

One point that needs to be taken into account is the social origin of the students, which often influences their choice of studies. In 2020, in France, 41.0% of university students were social grant-holders.<sup>18</sup> In the sciences, the proportion was 42.2% in Licence programs (equivalent to a Bachelor’s)  
75        and 28.5% in Master’s programs while in engineering schools, it was 22.8%. Among the most prestigious « grandes écoles », the figures were 21.0% for ENS, 12.3% for Ecole Polytechnique and 10.3% for ESPCI-Université PSL.<sup>19</sup> Considering students’ social background, 33.1% of university students come from managerial or intellectual backgrounds (rising from 29.0% at Licence level to 39.5% at the doctorate level), compared to 55.2% in engineering schools and 62.6% at ENS.<sup>18</sup>

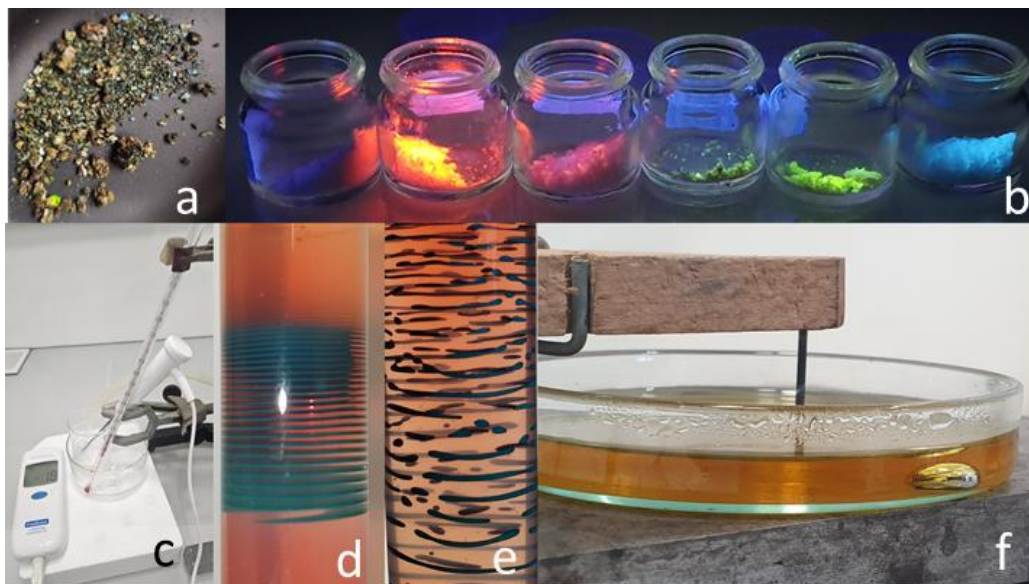
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80 The University of Montpellier<sup>20a</sup> has around 52,000 students enrolled across all fields of study. It remains one of France's top-ranked universities, consistently placing in the top 200 of the Shanghai Ranking, which primarily reflects the quality of its research. The Faculty of Science is one of the largest faculties within the University of Montpellier. Each year, approximately 8,000 students enrol in a wide range of courses spanning both fundamental and applied scientific disciplines, including  
85 mathematics, computer science, mechanical engineering, electronics and electrical engineering, physics, chemistry, geology, biology, and environmental science. <sup>20b</sup>

## THE FRENCH CHEMISTS' TOURNAMENT

### Overview of the Organization and Flow of the tournament

The French Chemists' Tournament has been running since 2021. Similar to the Chemistry  
90 Olympiads, which have both national and international editions, the Chemists' Tournament also features an international version. <sup>21</sup> Regarding its French version, it is organized by several “grandes écoles” (Chimie ParisTech-PSL, Ecole Polytechnique, ENS Lyon, ENS-Ulm, ESPCI-Université PSL) and universities (Sorbonne Université, Université-ENS Paris Saclay, Université de Montpellier, Université Paris Cité), as well as the French-speaking Canadian University of Sherbrooke. Teams bring together 3<sup>rd</sup>-  
95 year Licence and/or 1<sup>st</sup>-year Master students. Ten teams of six candidates compete. For six months, each institution prepares its team on eight topics, which can be described as open-ended problems. These topics encompass various areas of chemistry – often multidisciplinary, with potential connections to physics, biology, or the history of science – and current research challenges. The issues posed guide students towards scientific approaches, integrating methodological aspects such as bibliographical work,  
100 lab experiments, analysis, interpretation, and communication. These topics, designed to spark students' interest, bridge the gap between research and teaching, and are broad enough to allow for multiple approaches or alternatives. Examples include synthesizing thermoplastic wood from a green chemistry perspective or elaborating magnetic jewellery (Figure 1).



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**Figure 1:** Examples of student achievements to respond to the chemist Tournament subjects include: a) magnetic opal gem to answer the question “How to make magnetic jewels?”, b) fluorescent materials to answer the question “how to see invisible light?” , c) super self-cooling kit to answer the question “how to cool your drinks?”, d) breaking parity patterning and e) self-patterning to answer the question “How to recreate patterning observed in nature and animals?”, f) oscillating gallium “beating heart” (clock) to answer the question “how to measure time with chemistry?”.

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Students begin by proposing specifications and conducting bibliographical research. With the guidance of their supervisors, they explore technical and/or theoretical solutions, trying or succeeding to create a prototype. They then prepare a 12-minute presentation of their work. The tournament lasts two days and takes place at the end of March, with each team taking part in four matches. At each meeting, two teams face off, alternating between the roles of “orator” and “contradictor”. One team chooses a representative speaker, and the other appoints an opponent. The presentation is delivered in French, with the orator using a pre-prepared projected presentation and the contradictor team preparing a live response during the orator’s presentation. More extensive examples of topics covered in the presentations are given in the article by Piard *et al.*<sup>22</sup> These presentations are true scientific debates, in the style of “verbal jousting”. The presenting team’s goal is to clearly present and justify their scientific

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approach to the problem, drawing on their bibliographic research, scientific investigations and results (speaker). The opposing team must then provide constructive criticism, highlighting the strengths and weaknesses of the presentation while also suggesting areas for improvement. A discussion follows between the two teams, now involving all their members.

A panel of academic experts – comprising researchers, teacher-researchers, higher education lecturers, chemical industry researchers and managers – asks questions to both teams ('orator' and 'contradictor') following the verbal jousting. This panel is responsible for evaluating the quality of the debate and assigning grades to the teams.

At the University of Montpellier, student volunteers are typically drawn from the Chemistry Master 1 "Projet Professionalisant" program. The preparation for the scientific competition involves several key stages. First, students, guided by their teachers, explore the relevant topics and issues, identifying challenges and initial solutions. They use bibliographic databases such as SciFinder and Web of Science to gain an overview of the project and to develop an experimental plan that meets the outlined objectives. The second phase focuses on conducting experiments through a semester-long research project, totalling 32 hours. Students engage in hands-onwork that includes the synthesis, characterization, and analysis of materials or molecules. The final stage involves creating presentation materials and preparing a discourse that addresses their research question. This phase occurs from December to March, with initial 2-hour weekly sessions increasing to two 2-hour sessions per week as the tournament approaches, totalling approximately 28 hours, supplemented by additional lab sessions to refine experimental projects. Emphasis is placed on developing oral communication skills, requiring students to present their topics clearly and persuasively within a 12-minute timeframe. They also practice adaptability in responding to questions from an audience, with diverse academic backgrounds. Critical thinking is fostered, both for presenters defending their ideas and for the audience engaging in critical analysis of the proposed approaches. This exercise, coordinated by teachers, occurs in a supportive environment that encourages collaboration and camaraderie, enhanced by the provision of free pizzas as an incentive. This approach ensures students are well-prepared for upcoming scientific oratory competitions.

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## The Chemists' Tournament as a Learning Experience

The aim of this tournament is to enhance the students' scientific culture, knowledge and communication skills, both during the preparation phase and throughout the event itself. This approach parallels the inquiry-based learning method used in secondary schools<sup>23,24</sup> or previously implemented at our university through the "Chimie Science Magique" program<sup>25-28</sup> and "Projet tuteuré".<sup>29-31</sup> Indeed, this teaching is student-centred, requiring students to use experimental skills to answer scientific questions, construct arguments to respond to questions from opposing teams, and demonstrate a certain autonomy and critical thinking skills. This experience not only generates new knowledge for the students, but also develops related skills, such as specific lab skills, communicating results, exchanging ideas with peers and with those involved in research and teaching, developing a taste for science and thus increasing motivation for science.<sup>25</sup> The tournament's national subjects are written by organizing committee members in a challenging way, beginning with a stimulating prompt (*e.g.*, "When hens have teeth") that motivates students to first conduct an extensive literature review, then exchange ideas with peers and supervisors, and carry out specific experiments, synthesis and analysis in the teaching labs with a high degree of autonomy (even if supervised by instructors). During the tournament, these exchanges take place between the orator and opposing teams, as well as with the jury. This process demands strong communication skills, in-depth chemical knowledge and critical thinking, enabling students to develop new abilities. Much like the investigative approach, students identify a problem or research question, formulate hypotheses, and test them, usually through experiments. They collect, analyze and interpret data, draw conclusions and, if these are not satisfactory, revise their hypotheses and begin the process anew. This can be seen as a research-based training, allowing students not only to expand their knowledge but also, to hone their ability to present and discuss their findings as scientists do, and often leading to new hypotheses that require further investigation.<sup>32</sup> An additional benefit for students in the University Master's program would be the boost in their self-esteem, since most of them come from less privileged backgrounds (often, unfortunately, associated with lower career expectations) compared to students from "grandes écoles" who are frequently considered the elite from a very young age. The tournament would also serve as a means to boost self-confidence for Master's Students, helping to form a cohort of highly trained and confident students<sup>1,5,33</sup>.

## METHODOLOGY

To find out how students at the University of Montpellier felt about their experience participating in the French Chemists' Tournament, we developed a questionnaire (forty-three statements in French) divided into four sections: knowledge, personal knowledge, difficulties/work capacity, interest/motivation (see SI-2 "the questionnaire", p. S3-S7). The questions were written by chemical education researchers and approved by instructors. They were tested with seven students during the first year the University of Montpellier took part in the French Chemists' Tournament in 2022, to ensure that the questions were understandable and usable. One question was removed, and these 190 students were not included in our final results. Then, thirteen French Chemistry undergraduate students (seven males and six females, approximately 21-22 years old) from the University of Montpellier participated in the Tournament in March 2023 and March 2024 (two students from the 3<sup>rd</sup> year of the chemistry Bachelor's program and eleven students from the first year of the Master's program in materials chemistry, biomolecular chemistry or computational chemistry). After the end of the Tournament, instructors invited students to voluntarily evaluate this experience by completing an 195 electronic form containing forty-three statements with responses based on a Likert scale.<sup>34</sup> Answers are given on a 5-point Likert scale (totally disagree, disagree, neither agree nor disagree, agree and totally agree).

Individual interviews were conducted with the students, each time by a single researcher external 200 to the tournament instructor's team (see SI-3 "Interview protocol", p. S7). The students who participated in the interviews did so voluntarily, impartially and spontaneously. We invited students to take part in the interviews, without making them mandatory; only those who wished to did so. They were informed that their comments might be used in a scientific article, and they consented to this. Only the chemistry education researcher (who is fully independent from the tournament preparation and has no prior contact with the students before the interview) conducting the interviews knows the 205 identity of the participants. This approach allowed students to express themselves freely. Seven

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students agreed to participate. The interviews were recorded and manually transcribed verbatim. Each interview lasted an average of twenty minutes and was divided into two parts. First, the students freely discussed how they felt about the tournament during the preparation phase, during the tournament itself, and afterwards, as well as the impact of this experience on their knowledge and skills. Secondly, the students were asked about a series of transferable skills (such as stress management, time management, oral communication, problem-solving skills, critical thinking, scientific argumentation...) and personal attributes (such as motivation, self-confidence, curiosity, autonomy, trust in others, enterprising spirit). They were asked if and how the tournament has influenced the development of these skills. For the analysis, we focused on the skills or personal attributes that the majority of students identified during the first stage of the interview, *i.e.* the time when they freely expressed their feelings about the tournament (before, during and after). We have identified the skills most frequently cited by students.

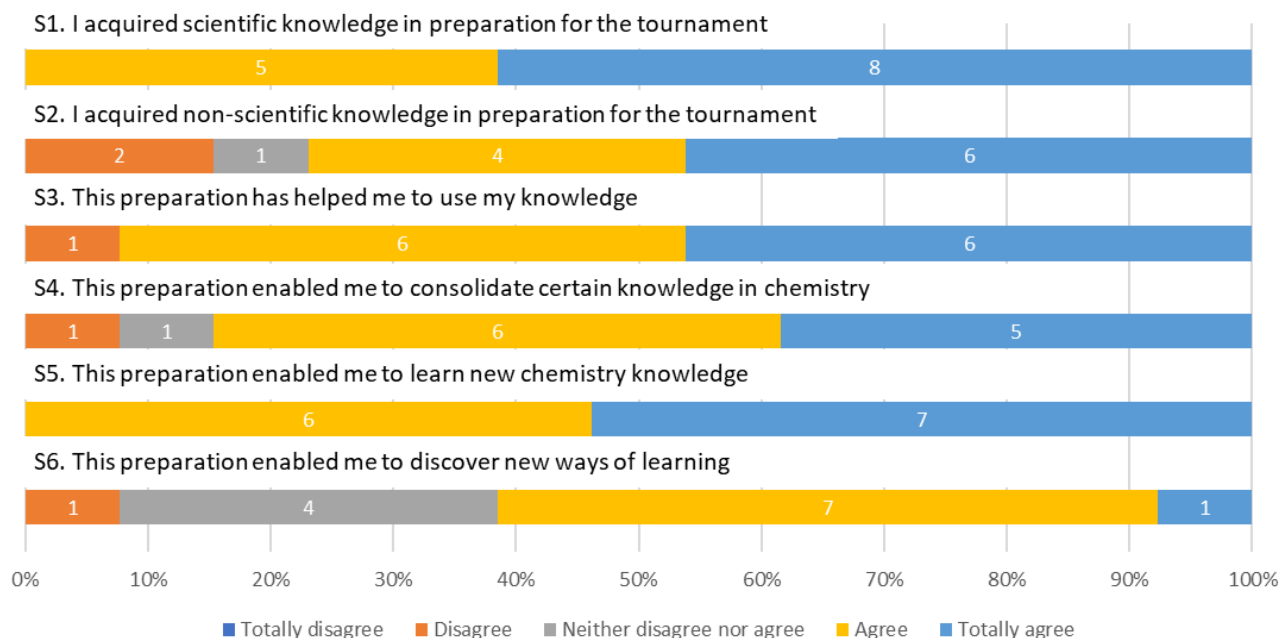
No formal ethical approval was required, as the study was conducted under a general institutional protocol for classroom activities. Informed consent was obtained from all participating students. They agreed that the data collected (questionnaire and interview) would be used solely for scientific purposes. The publication and communication of the results will ensure the strictest anonymity of participants.

## **EVALUATION OF THE TOURNAMENT-STUDENTS' PERCEPTIONS**

Figures 2-5 present the results collected from the students who participated in the chemistry tournament, focusing on various aspects of disciplinary knowledge.

### **About knowledge**

All the students reported having acquired scientific knowledge during the preparation for the tournament (S1, S5), and ten out of thirteen stated that they had also acquired non-scientific knowledge (S2). This preparation helped them apply their knowledge (twelve out of thirteen, S3) and consolidate certain skills (eleven out of thirteen, S4). Eight out of thirteen students reported discovering new ways of learning (S6).



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**Figure 2: Knowledge:** Distribution of students' responses to survey statements who participated in the Tournament (N=13). The numbers represent students' responses on a five-point Likert-type scale that ranges from "totally disagree" to "totally agree".

### About Personal Knowledge

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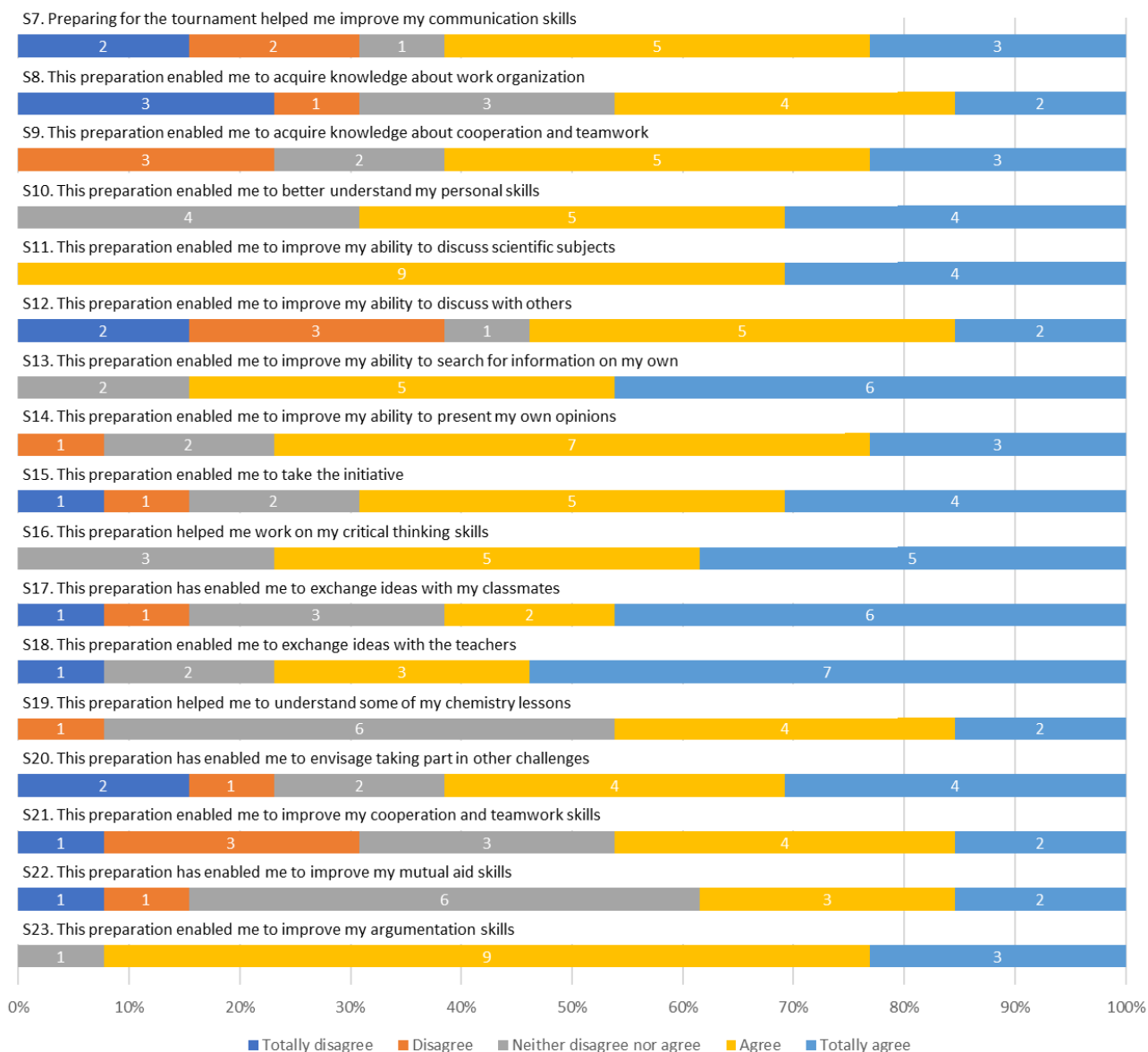
Other non-disciplinary skills were also acquired such as communication, organization, cooperation, self-confidence and autonomy. Regarding communication, eight out of thirteen students reported that this preparation helped them improve their communication skills (S7), seven out of thirteen felt it improved their ability to engage in discussions with others (S12), eight out of thirteen students reported exchanging ideas more frequently with their classmates (S17), ten out of thirteen students increased their interactions with teachers (S18), and all participants felt more capable of discussing scientific subjects (S11). In terms of organization, six out of thirteen students stated that the preparation helped them acquire knowledge related to work organization (S8). For cooperation, eight out of thirteen students reported gaining a better understanding of cooperation and teamwork (S9), but this did not necessarily translate into skill acquisition, as only six out of thirteen students responded positively regarding their cooperative skills (S21). Only five out of thirteen students reported an improvement in their mutual aid skills (S22). Concerning self-confidence, nine out of thirteen

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indicated that the preparation helped them better understand their personal abilities (S10), ten out of thirteen felt confident presenting their own opinions (S14) and nine out of thirteen students reported taking more initiative (S15). Additionally, ten out of thirteen students worked on their critical thinking skills (S16), eight out of thirteen students felt ready to participate in other challenges (S20) and twelve out of thirteen students reported that the preparation helped them improve their argumentation abilities (S23). Regarding autonomy, eleven out of thirteen students reported that they sought information on their own (S13). However, only six out of thirteen students believed that the preparation helped them better understand their chemistry courses, while another six out of thirteen expressed no opinion on the matter (S19), possibly due to the topics differing from those covered in the lectures.



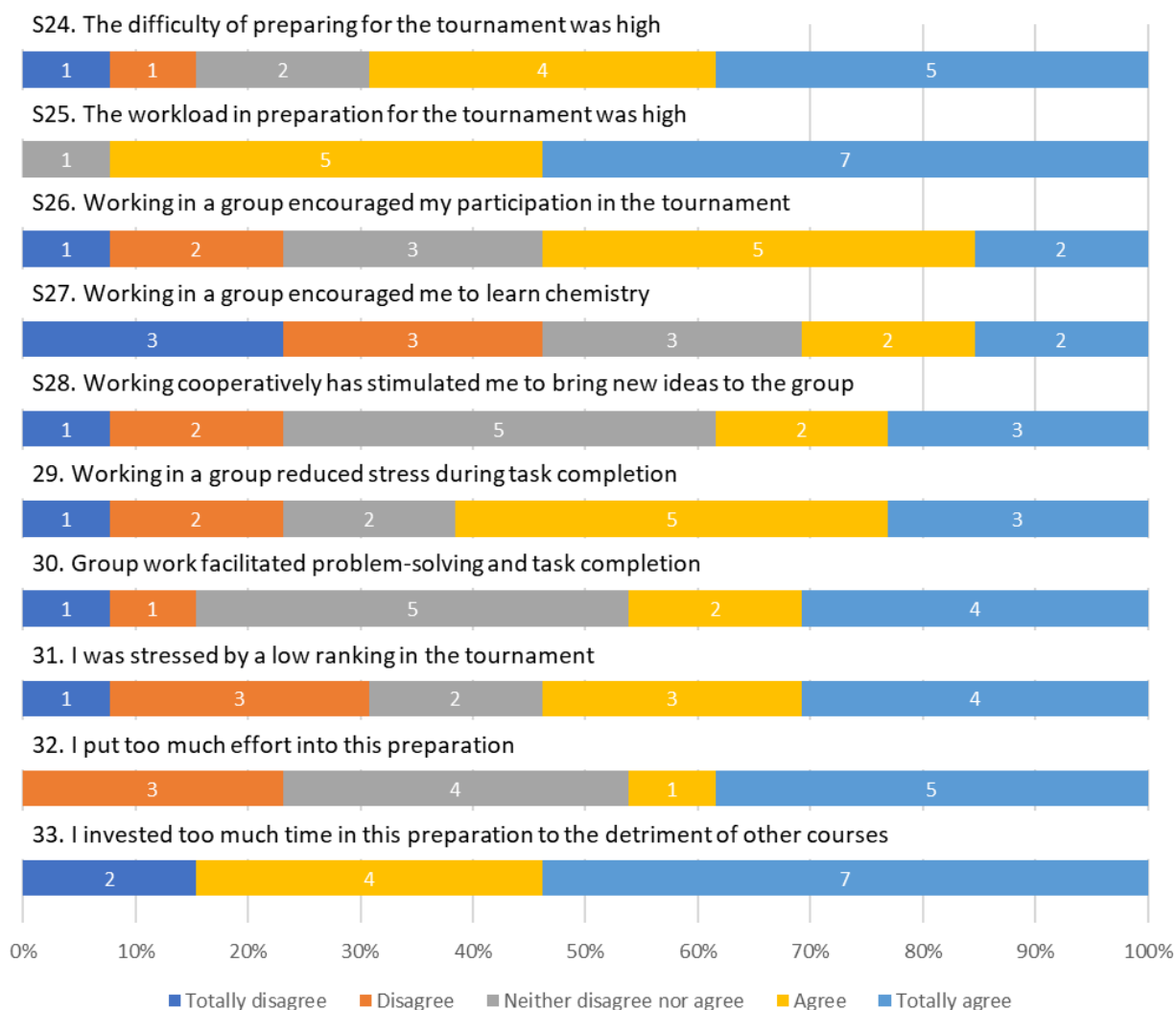
**Figure 3: Personal knowledge:** Distribution of students' responses to survey statements who participated in the Tournament (N=13). The numbers represent students' responses on a five-point Likert-type scale that ranges from "totally disagree" to "totally agree".

#### About difficulties and ability to work

Regarding the challenges, nine out of thirteen students found it challenging to prepare for the tournament (S24), twelve out of thirteen felt that the workload during the preparation of the tournament was high (S25), six out of thirteen believed they had put too much effort into this

270 preparation (S32), and eleven out of thirteen students felt they had spent too much time on it to the detriment of other courses (S33).

Group work encouraged their participation in the tournament for seven out of thirteen students (S26), and eight out of thirteen students felt that working in a group reduced stress during task completion (S29). However, group work did not motivate all students to learn chemistry (with only four out of thirteen expressing such motivation) (S27), and only five out of thirteen felt it encouraged them to contribute new ideas to the group (S28). Additionally, six out of thirteen students reported that group work facilitated problem-solving and task completion (S30) and seven out of thirteen students were stressed about receiving a low ranking in the tournament (S31).



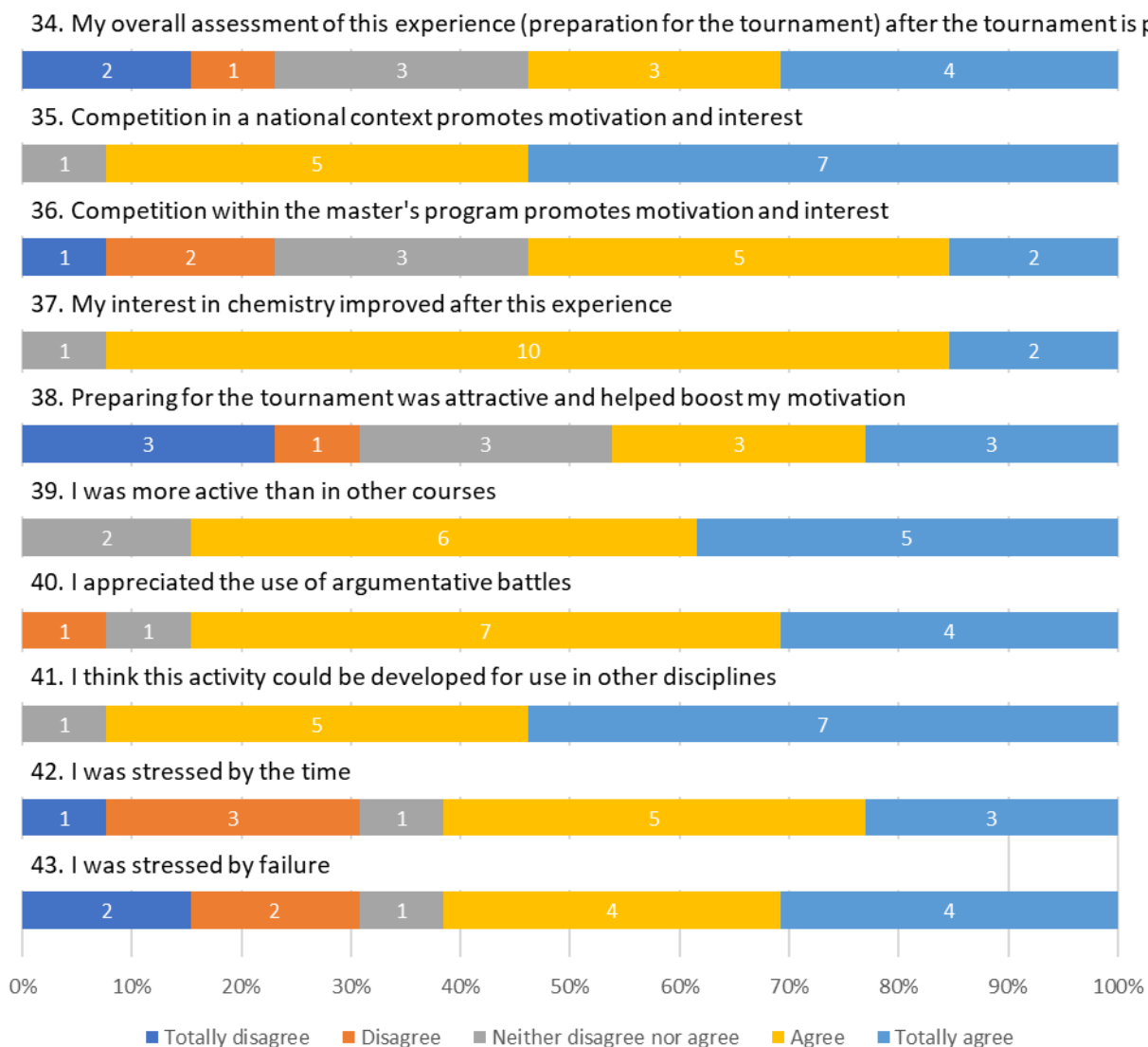
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**Figure 4: Difficulties/ability to work:** Distribution of students' responses to survey statements who participated in the Tournament (N=13). The numbers represent students' responses on a five-point Likert-type scale that ranges from "totally disagree" to "totally agree".

#### About Interest and motivation

285 In terms of interest and motivation, seven out of thirteen students found the preparation for the tournament to be a positive experience (S34). In fact, twelve out of thirteen students felt that competing in a national context fostered motivation and interest (S35). By contrast, only seven out of thirteen expressed the same level of motivation within the Master's program itself (S36). Twelve out of thirteen students reported an increased interest in chemistry after this preparation (S37) and eleven  
290 out of thirteen students felt more engaged and active compared to their other courses (S39). Eleven out of thirteen students enjoyed the use of argumentative battles (S40), and twelve out of thirteen students believed that similar activities could be beneficial in other disciplines, this activity could be developed for use in other disciplines (S41). Six students reported that preparing for the tournament was appealing and helped boost their motivation (S38). However, eight out of thirteen students felt  
295 stressed by time constraints (S42) and eight out of thirteen students were anxious about the possibility of failure (S43).



**Figure 5: Interest/motivation:** Distribution of students' responses to survey statements who participated in the Tournament (N=13). The numbers represent students' responses on a five-point Likert-type scale that ranges from "totally disagree" to "totally agree".

### About interviews

When students were invited to express their views on the tournament, several points emerged as common ground:

- Students reported feeling more comfortable speaking, and are less afraid of expressing themselves orally, even the shyest among them. Their oral communication skills had improved, a

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change that was also noticed during interviews such as when presenting their internship or applying for PhD programs.

310 - They discovered what research entails and unanimously agreed that they had learned how to conduct bibliographic research using appropriate tools.

- Group work was frequently mentioned, with team spirit playing a key role in supporting one another and deepening understanding of certain disciplinary concepts.

- Self-confidence was another key point, with many stating that the tournament pushed them out of their comfort zone and gave them a sense of responsibility. Indeed, during debates, each student spoke on behalf of the team, which placed a certain pressure on their shoulders. The interviewed students expressed pride in having dared to participate in such an event.

For them, it also represented a valuable asset on their CV, enhancing their chances of being selected for doctoral programs.

320 When guided during the second part of the interview, students identified the following soft skills:

- motivation: because the topics were new and original for the students, they were eager to embrace the challenge of solving problems and defeating their opponents. Some even felt the spirit of a researcher within them.

- curiosity: because the knowledge was different from that learned in class, and the subjects were vague yet intriguing, students engaged in extensive bibliographic research.

325 - students were expected to work autonomously, organizing their bibliographic research, planning experiments, and testing them in the laboratory.

## **CONCLUSION**

330 First and foremost, due to the small number of students in the sample, the results may only suggest a trend, making it necessary to increase the sample size in order to draw statistically significant conclusions.

Over the three years that the University of Montpellier has participated in the French Chemists' Tournament, we have observed that students acquire a broad range of skills and knowledge through their preparation for and participation in this competition. Working on diverse chemistry topics has

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naturally allowed them to extend or consolidate their knowledge in the field. They also develop work methods, autonomy, and critical thinking skills, while learning to communicate effectively with their peers and researchers. The argumentative battles not only enable them to engage in these exchanges, but also encourage students to delve deeper into specific scientific subjects, sharpening their critical thinking in the process. As a result, they gain significant self-confidence. Notably, most of the participants have since advanced to the doctoral level. Although the tournament and its preparation are demanding in terms of workload and stress, the benefits of the group work and the competition are substantial.

As already demonstrated in the literature, active learning methods such as challenges, as opposed to one-way communication, lead to better learning. These outcomes are further enhanced by increased motivation (the students interviewed were unanimous on this point), which drives students to deepen their knowledge and engage in debate, leading them to explore the subjects more thoroughly. In the context of the tournament, collaboration and competition are two additional factors that significantly enhance learning. Indeed, the interviews revealed a strong team spirit and a desire to succeed in the competition, which enabled the students to surpass themselves and learn even more.

In 2022, the University of Montpellier finished in third place, surpassing prestigious “grandes écoles” such as Ecole Polytechnique and ENS Lyon. The rigorous preparation and motivation generated by the competition enabled the students to meet the high standards of these elite institutions. Furthermore, the tournament allows individual students to showcase their skills to professionals from both academia and industry, opening doors to internship positions and other opportunities that might otherwise have been out of reach – an invaluable asset for their future careers. Additionally, it provides a unique opportunity to highlight the quality of our students' training to professionals in both academia and industry. Indeed, the students interviewed stated that the tournament was an asset in their recruitment as doctoral candidates. The tournament enabled many students to discover their potential, gain self-confidence, and consider career paths they hadn't previously imagined. It clearly demonstrates that high-quality students can be found in non-elitist institutions and can be brought to the level of any national elite within a few months of work on both scientific and non-scientific skills.

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We have seen that tournaments can have a positive impact on students' acquisition of various  
365 skills. Of course, organizing inter-university tournaments may be challenging, but this kind of  
competition could nevertheless be considered within high schools or universities.

## ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available on the ACS Publications website at DOI:

370 10.1021/acs.jchemed.XXXXXXX. **ACS will fill this in.** [The French higher education system and the  
questionnaire.](#)

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