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Tournament of Young Chemists in Ukraine: Engaging Students in Chemistry through a Role-Playing Game-Style Competition

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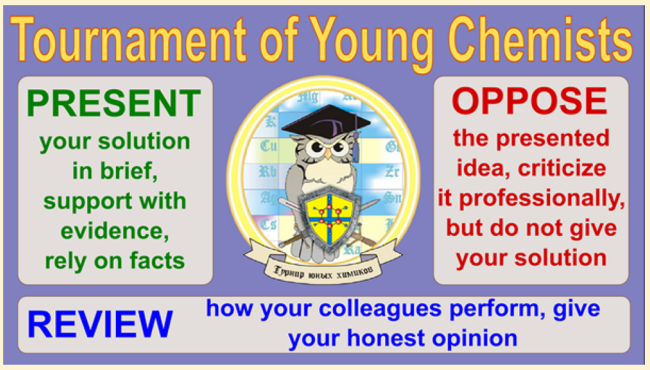
ABSTRACT: With more than 20 years of history, the Tournament of Young Chemists is an innovative, cross-disciplinary competition that promulgates the everyday life of scientists into the classrooms and on the contest stage. Original, open-type problems, unrestricted access to scientific data sources, and personal interaction with researchers from different fields of chemistry aim to develop a broad range of skills that prepare the participants for their future academic endeavors such as thinking, communication, reasoning, and teamwork.



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INTRODUCTION

Science competitions, particularly for middle and high school students, became an essential part of modern educational systems for many countries around the globe. These range from traditional subject Olympiads in various dosciplines[1] that have an extensive multilevel hierarchy, originating at the local school and culminating in large international competitions, to relatively newer competitions such as science fairs and research projects contests,[2,3] to more interactive[4] and even Internet-based competitions.[5] Usually, the main goal of these competitions is to select the brightest and most promising students and encourage them on a course to a successful development of their talents. Another important goal is to promote various disciplines through the competitions, igniting the spark of curiosity in students' minds and providing them with the tools to pursue such curiosity. Results of different competitions are usually in consistent accordance with further students' performance at the university level[6] and are often used to help assessing the level of education offered by a given educational institution.[7] The development of new interactive approaches is driven by the need to complement the efforts in assessment, development, and promotion of academic problem-solving and reasoning skills provided by the subject Olympiads. Although being a reputable and recognized academic competition, Olympiads oftentimes lack live interaction between participants and their colleagues and do not usually favor team work skills that are, without doubt, very important for the professional development of a highly qualified specialist.

We hereby discuss a successful experience of an integral chemistry competition in a form of a role-playing game that models the real-life research process and subsequent interactions between peers in the scientific community. This type of competition is designed to develop a broad range of competencies and skills, is cross-disciplinary by nature, and can be easily incorporated into the learning process at any education level.

HISTORY OF TOURNAMENTS

Science tournaments as an original type of competition for middle and high school students appeared at the end of the 1980s in Lomonosov Moscow State University in Russia, which was then part of the Soviet Union. The first and most successful tournament was organized in the discipline of physics and grew to become what is now widely known as the International Young Physicists' Tournament.[8] A tournament is a team academic competition (with elements of individual competition) where the participants use, besides the basic knowledge of the subject, their advanced skills, which include literature searching, scientific reasoning, presentation, etc. The problems are usually published in open sources well in advance (about 6 months before the competition), and many of them do not have a definite solution (whereas some can have no solution at all). The participants defend their ideas during a live discussion

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with their peers and professional researchers and teachers who judge the tournament.

This idea attracted widespread attention and was welcomed with enthusiasm in the educators' community, as the tournament managed to integrate the most dynamic and important aspects of both innovative education and real-life science. Intriguing search for a scientific solution of a certain problem, mastering the concepts, and learning to apply fundamental knowledge, as well as convincing rhetoric, interaction with the audience skills, and simply excitement and passion for a live discussion, are all ultimate parts of the Tournament. In Ukraine, this idea was readily adopted first by enthusiasts from the Odessa State University and the Richelieu Lyceum, who successfully participated in State-wide followed by International tournaments of young physicists.

CHEMISTRY TOURNAMENTS IN UKRAINE

Overview

Very soon, the leading chemistry educators joined the tournament community. The first chemistry tournament in Ukraine took place in Odessa in 1989, with a regional perspective, and welcomed four teams, but this was only the beginning. As the news spread and more teams became involved, the competition gained broad popularity among both teachers and school students. In 1994, the first Ukrainian National Tournament of Young Chemists (TYC) took place. Honoring its roots, the first nationwide TYCs took place in Odessa. However, starting from 1997, the tournaments traveled from one Ukrainian city to another every year. Although preparation for the tournament is considerably different from (and sometimes quite more challenging than) preparation to participate in a subject Olympiad, tournaments became more and more popular (see Figure 1). In the past years, the number

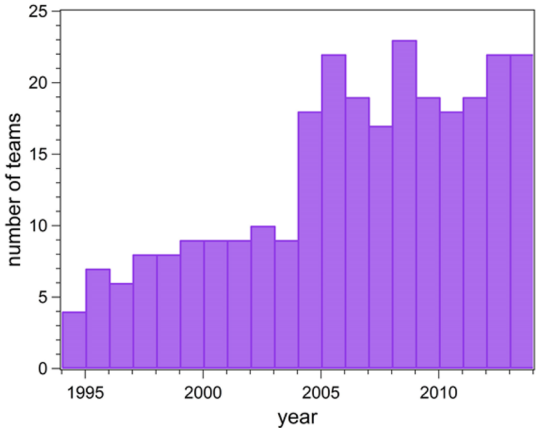

Figure 1. Number of teams participating in the Ukrainian National Tournament of Young Chemists (an approximately two-fold increase of participation can be seen as a result of improvements introduced by a new leadership team, inducted at the end of 2002).

of participants has increased significantly, and international participation has been a tradition since 2006. Although there is no direct preselection of teams for the National Tournament (at this time, any team can register for participation in the National Tournament, even if the team did not participate in a regional tournament); competitions are also organized at regional and even district levels in many parts of the country. Additionally, educators from other disciplines joined the movement: biologists, economists, engineers, etc., totaling nine subject tournaments held in Ukraine annually. For example, the experience of the Ukrainian National TYC gave rise to the Tournament of Young Biologists in Ukraine and then in Russia, and the Armenian Tournament of Young Chemists was also inspired by a few successful participations of Armenian guest teams in the TYC in Ukraine.[9]

Such a multidimensional competition has a number of advantages over traditional subject Olympiads. First of all, the problems being published half a year before the Tournament allow enough time for the teams and their leaders to analyze the questions, perform a detailed literature search, formulate models of the solutions, and develop underlying hypotheses, discuss, and prepare logical solutions well supported with facts and evidence, and finally illustrate the reports with informative visual material. Additionally, teams can seek advice from specialists in the field affiliated with any research or educational institution. While usually every problem is assigned to one team member, the teamwork is crucial at both the preparation stage and during the Chemical Fight (in fact, the strategy of teamwork during the Fight can itself be a topic of a separate paper). The live interaction of the participants with their peers is one of the key parts of the competition. Participants can thus develop an important set of practical skills including verbal expression, effective communication, and interacting with the audience. Additionally, participants acquire real-life experience in presenting their arguments in a convincing way as well as dealing with questions and counter-arguments of the opponents. Participants also have a chance to interact with the judges who, being experienced researchers or talented teachers, act as role models, share their knowledge, passion, and enthusiasm, and inspire the representatives of the future generation to pursue sciences. In total, the Tournament can be viewed as an instructive interactive model of the real research process, beginning with the formulation of the problem, followed by the research process, and crowned with the presentation of one's findings to the judgment of a broad audience of one's peers.

Problems

By promoting original and creative thinking, the Tournament offers participants a profoundly new type of problems that are very much different from those usually offered in the traditional classroom setting or at the chemistry Olympiads. The main requirement for a problem to be suitable for the tournament is that it should not have a single specific answer or solution (the questions below exemplify those offered to participants in the Ukrainian National TYCs in the past two decades).

Chronometer. Describe a construction of a chemical "stopwatch" that will work indefinitely and will produce a regular signal with a certain predefined time period.

Supercompound. Imagine a molecule that consists of the atoms of as many different stable chemical elements as possible. Describe the synthetic path to obtain such a molecule.

Moreover, the most interesting problems are usually related to the actual problem of chemistry, materials science, pharmacy, ecology, etc.

Water Blanket. In the areas with hot and dry climate, the problem of water evaporation from the surface of open water reservoirs is very important.

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Suggest an environment-friendly and nontoxic composition and method of its deposition as an ultrathin layer on the water surface, which will prevent or decrease the loss of water due to evaporation.

Suntan. Design a chemical indicator (that you can directly apply to the skin) capable of controlling the dose of the solar radiation obtained by a sunbather.

Some of the questions contain science fiction elements to go beyond the commonplace and allow the students to use their imagination to its full potential while remaining within the realms of realistic science.

SETI. When time will come for humanity to encounter an extraterrestrial civilization, they will most probably not understand our language. Suggest a way to fully describe the ecosystem of our planet and the level of technological development of our civilization by the means and using the language of chemistry.

Time Machine. How would you organize the production of the Aspirin pills in times of Julius Caesar?

Often times, the most unexpected and interesting discussions of science occur when the students present their solutions for problems that were specifically designed not to have any solution at all:

Alkahest. Beside the "philosophers' stone", ancient alchemists also tried to synthesize alkahest, a universal solvent. Is it possible that a compound capable of solving everything exists? Which properties should a molecule of such compound have?

This approach presents a strong challenge to students, whose traditional psychology is often built on the concept that there can be no mistake in a problem, whether it is encountered at school, on an exam, or at the competition, and therefore the problem must have a solution. Therefore, it is a matter of academic and scientific maturity of a student to take this challenge, to make the statement that there is no solution to a particular problem, and to further prove it by meeting all the criteria for a scientifically supported hypothesis.

Jury

A strong and devoted leadership team and professional judges are paramount for a successful tournament. The integral and cross-disciplinary nature of tournaments require the judges to be able to professionally assess many various aspects of the team performance as well as individual contribution of team members. This may include, but is not limited to, quality of the model of the problem solution, theoretical and experimental evidence supporting the model, clarity of presentation and reasoning, involvement in the discussion, and the quality of the answers given to the peers/judges questions, etc. It is thus critical for judges to be well versed in various areas of chemistry and other sciences, which is why specialists in biology, physics, and medicine with advanced knowledge in chemistry are often invited to the Jury. Some original Tournament founders remain active judges, while many other judges serve with acumen acquired through over a decade or more of dedication to the Tournaments. The National TYC Jury traditionally consists of approximately $^{2}/_{3}$ of permanent members recommended by its Chair, and the remaining $^{1}/_{3}$ is formed by rotating members who are usually recommended by the Chair of the Local Organizing Committee and include local high school teachers, college professors, and researchers. It is worth noting that a significant portion of judges are former Tournament participants themselves, many of whom are successful university students, and some who have already earned Doctoral degrees and joined the scientific community as researchers or educators. Many of former participants maintain their connection with the Tournament by training their own teams or by consulting the coaches and participants and helping them to show the highest level of their knowledge and erudition.

The Fight

For the Tournament, teams consist of 3−5 high school students (one of whom acting as a Captain) led by a team leader or coach. Usually, the National TYC starts with preselection (quarterfinals), when the teams are given an opportunity to test their skills against as many other competitors as possible, with as few repeated encounters as possible. The top 50% of the teams then progress to the semifinals. After this stage, the runner-ups are awarded with third-place diplomas, and the winners meet during the Final Fight to compete for first and second place.

The "Chemical Fight" (CF) is the central piece of the Tournament action. Usually, three teams take part in a Fight, but occasionally participation of four teams is possible. Fights between two teams are exceptionally rare in modern practice. Each CF consists of Rounds (Figure 2), and the number of

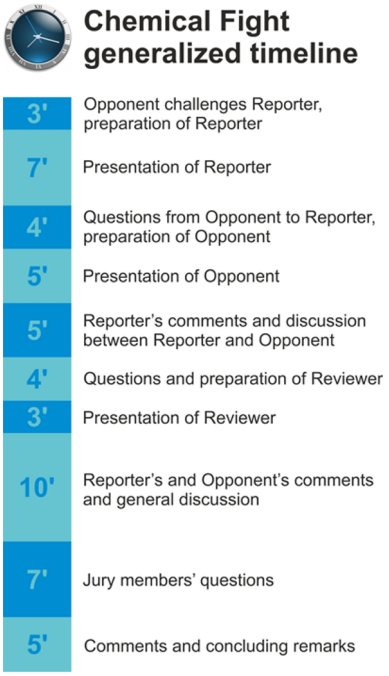

Figure 2. On the basis of a more than two-decade practice, a scenario has been created to organize every Round of a Chemical Fight.

Rounds corresponds to the number of the participating teams. During each Round, each team plays the role of either a Reporter, an Opponent, or a Reviewer (and a nonacting Observer if a fourth team is present). The roles change on a rotating basis to ensure each team assumes all three roles during one Fight.

In the beginning of the Round, the Opponent challenges the Reporter by asking the corresponding team to present their

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solution for the problem of the Opponent's choice. The Reporter team has the right to either accept or decline the challenge (with restrictions). In the latter case, the Opponent has to challenge their counterpart with an alternative problem from the list. After the acceptance of the problem, the Reporter appoints one (sometimes two, with restrictions) team member to act on behalf of the team during this particular Round, who then presents the team's solution to the audience. The main goal of the Reporter is to explicitly define the solution concept and model and to present the detailed solution, emphasizing the chemical aspect particularly. It is always beneficial for the Reporter to illustrate his or her presentation with the slides, pictures, or video. After a brief opportunity to ask clarifying questions (with no discussion), the Opponent team also appoints its representative, who provides a critical point of view regarding the Reporter's solution. The main role of the Opponent is to point out the strengths and reveal the weaknesses and inconsistencies of the Reporter's solution as well as to ask questions that will lead to a fruitful discussion. It is important to remember, however, that the Opponent can only discuss the Reporter's solution without suggesting his or her own approaches to solve the problem of interest. It is the Opponent's task to assess whether or not the Reporter has completely and adequately solved the problem. After the Opponent's presentation, a short discussion between the Reporter and the Opponent takes place, which involves only the representatives from the two teams. Then the Reviewer team is allowed to ask clarifying questions to both Reporter and Opponent. Following the clarification questions, a representative of the Reviewer team joins his or her colleagues on the stage to present a professional and unbiased review of the Reporter and Opponent's performance during their presentations and subsequent discussion. The Reviewer provides his or her judgment on how well his or her colleagues performed their functions as Reporter and Opponent as well as regarding the quality of their discussion. After a short general polemic between their representatives, the teams are then given an opportunity to provide additional comments and ask questions. This is the last opportunity for teams and their representatives to clarify the details, as this part of the Round concludes their communication between each other.

After a long and multiversed presentation of the problem's solution, its critical analysis, and fruitful discussion, the judges are allowed to ask their questions. Usually, these are addressed to the team representatives on the stage. The questions are aimed to assess how well-versed the participants are in the particular topics related to the discussed problem and to clarify any remaining inconsistencies that have not been addressed during the discussion. Finally, the judges are ready to present their marks to the audience.

Results

At the end of every Round, each participant (and his or her team) is given a mark by each Jury member (usually there are 4−6 judges during the quarterfinals, 6−8 for the semifinals, and around 15 for the final Fight). The Reporter receives three marks in the following categories.

(1) Science: quality of the solution model, as well as the extent to which the problem is solved, is assessed together with the scientific accuracy and originality of the solution, its adequacy to the problem, quality of the illustrative material, logic, and completeness of the presentation.
(2) Discussion: the ability to start and maintain discussion, provide complete, logical, and competent answers to the questions, and team participation in the general discussion.
(3) Presentation: mastery of academic rhetoric skills, reasoning, and ability to communicate the ideas to the audience, ability to stress out the most important details, and ability to listen to the colleagues.

The performance of both Opponent and Reviewer is assessed in two categories.

(1) Analysis: the ability to analyze, quickly penetrate into the heart of the solution, elucidate both strengths and weaknesses of the proposed solution (for the Opponent), and professionally assess the performance of the Reporter and Opponent (for the Reviewer) as well as participation in the discussion of the team in general and its representative on the stage in particular.
(2) Presentation (same as for the Reporter).

The marks are given in the range from 3− to 5+, which are then converted into points (from 5−60) using a nonlinear conversion scheme. The goal of the latter is to provide a better distinction among the high-performance teams that do not compete with each other during the selection rounds. All marks for each participant are then weight-averaged to account for the noneven contribution of different categories into the final points total.

CONCLUDING REMARKS

The Tournament of Young Chemists is an innovative role-playing game-style science competition that, among its main goals, strives to emphatically promote the development of the most important skills for the school students' readiness for success in their further studies as well as future science research, education, and many other types of careers.[10]

The tournaments aim to educate and promote original thinking, multidisciplinary knowledge, teamwork, cooperation, and interaction among peers as well as with senior colleagues. We encourage our fellow educators to integrate this approach into classroom activities and also to promote the organization of such tournaments in the schools and on higher levels. Additional information about the rules, procedures, and sample problems and their solutions can be found on the TYC Web site[11] or by inquiry from the authors.

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Notes

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