Learning Through Competitions - The FIRA Youth Mission Impossible Competition*

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Abstract. This paper discusses challenges and opportunities when using competitions in robotics education. The authors describe the Federation of International RoboSports Association (FIRA) competition and, in particular, the FIRA Youth - Mission Impossible, an event targeted at overcoming problems of students consciously or thoughtlessly plagiarizing, by forcing students to solve previously unknown tasks. The paper shows an example of the positive influence robot competitions can have on cutting-edge research, even when targeted at younger roboticists. The FIRA Youth - Mission Impossible 2022 competition, where students had to measure the weight of bottles, and hence the wrench applied on the robot using only proprioception, inspired an initial approach and the creation of a practical test-bed for much more complex wrench estimation on hexapod robots.

Keywords: Educational Robot · Competition Design · FIRA · Mission Impossible · Wrench Estimation .

1 Introduction

Today, many problems threaten quality of life, such as climate change, air pollution, food shortage and poverty. Technology plays an essential role in overcoming these problems. Furthermore, since daily live is becoming increasingly dependent

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on technology, it is essential to train young people in their use, limits, and dangers. This paper focuses on intelligent robotics as one of the most relevant core technologies for the later part of the 21st century and beyond. Robot competitions can easily motivate teachers, students, hobbyists, researchers, and professors since cutting-edge technology can be developed using fun and challenging application domains.

Robot competitions, possibly based on a few existing real-world applications for may also act as an benchmark to evaluate current and guide future research. The importance of good benchmarks for intelligent robotics and AI research has already been discussed, and their important features are described in [13, 7–9]. Cleaning robots, autonomous driving, and delivery robots are the robotics applications that are probably closest to large-scale deployment. Other worthwhile applications like humanoid robots acting as autonomous firemen may still be many years away from reality.

The main contributions of this paper are as follows: In section 2 we highlight the danger of commercial entities influence robot competitions by providing specially designed hardware and software and thus "unfairly" tilting the playing field. Section 3 introduces the Federation of International Robosports Association (FIRA), the design of the FIRA Youth - Mission Impossible competition and describe the experiences of the Federation of International Robosports Association (FIRA) community with their leagues for those under 14 years old (U14) and under 19 years old (U19) participants [3]. Section 4 emphasises a specific implementation of the FIRA Mission Impossible competition that was developed to particularly ameliorate the danger of commercial influence by forcing students to develop solutions from scratch in a short time using similar hardware. An impact of the robot competition on serious research is exemplified in section 5, where research on external wrench estimation for the hexapod walking robot is sketched. Section 6 concludes the paper and provides ideas for further development of robot competitions.

2 Influence of Companies on Robotic Competitions

The FIRA Youth competition includes leagues for robot sports, disaster recovery, and battle robots. One issue that the organizers noticed is that the rules of these leagues, as in many other robotics competitions too, are relatively static. Each year, the chairs and technical committees, responsible for the rules of their leagues, make only small adjustments. This leads to the problem of companies producing robot kits, specifically targeted at winning robot competitions.

Typically designers of educational robotics games carefully consider what hardware and software is available to the students targeted and what skills the students must develop. For example, building a robot for one of the most widely used competitions, a line follower or line tracker (see Fig. 1 left), can be done with a single or two light sensors. However, line-following with only one or two light sensors requires non-trivial algorithms and programming. Challenges increase for a path with intersections, holes, and color changes. It requires sensor reading, calibration, filtering, and high-level reasoning. On the other hand, several robot education kits from Chinese and Korean manufacturers include a light sensor array with six or more sensors (see Fig. 1 right), which simplifies the control problem significantly. Moreover, the kits also include high performance line-following software. Students can create a competitive entry by building the robot in the kit and by turning it on. The actual competition requires calibration and high level programming (e.g., `follow_line`, `turn_right_at_intersection()`, `follow_line()`).

Fig. 1: A typical line follower/tracker competition (on the left) requires non-trivial programming using only one or two light sensors but can be trivially solved with six sensor bars and their associated software (on the right).

Companies providing professionally developed and manufactured hardware and software for the exact competition environment tilts the playing field much more than students finding solutions online (i.e., the thoughtless plagiarism problem). Finding plans and software from various sources and of varying quality, often poorly documented, still requires the students to integrate and adapt their solutions.

One solution to the problem is limiting the hardware allowed in the competition by narrow specifications. For example, the FIRST Lego competition and the World Robot Olympics require students to build their solutions using Lego parts only [3, 6]. Another solution is to have different classes in the competition, e.g. one for the ubiquitous Lego educational robot kits and one for custom-developed solutions or introduce classes based on the cost of the robot.

In view of openness and fostering creativity of students, these approaches are unsatisfactory: i) discriminatory limiting building blocks to a fixed list of parts limits creativity and unconventional solutions. Comparing costs is close to impossible for international competitions as component prices and qualities vary significantly over the world. Moreover, some specific components may not be available in some regions.

Many students are exposed to robotics during extracurricular activities, outside the official curriculum of their education. Still, many schools attract clients with their successes in international robot competitions. Therefore, these schools often have teachers and/or parents developing high-quality solutions, often including custom hardware, for specific events and then teach students to install and tune their existing software rather than develop their own solutions. For example, one of the authors had 12-year-old students show their VHDL code for an FPGA-based hardware platform, which the students claimed to have developed independently. However, upon request, the students could not compile their code independently.

Collaboration between students, their teachers, and parents is a pedagogically valuable element in learning if underpinned with a respective concept. However, in order to acquire robotics knowledge and competencies, students should be be involved in relevant aspects of designing, implementing and debugging their robot and should have the time to explore the solution space of a given problem.

3 The Federation of International RoboSports Association

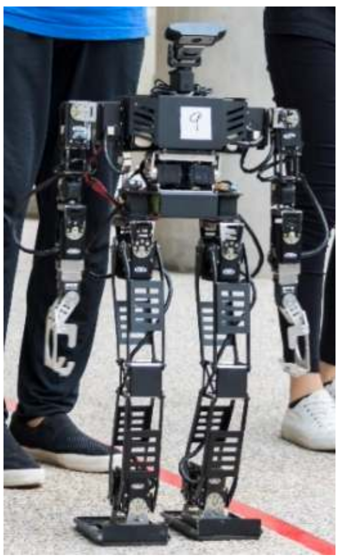
The Federation of International Robosports Association (FIRA) was founded by Prof. Jong-Hwan Kim from KAIST, Korea, in 1996. It is the oldest soccer robot competition in the world. Adding new leagues such as drones races and autonomous driving and new age categories include FIRA Youth for under 14 years old (U14) and under 19 years old (U19) under the new presidency of Prof. Jacky Baltes it has seen large growth. Now the annual FIRA Robot WorldCup competition regularly brings together about 1,200 participants of different ages. The aim of FIRA is to (a) provide benchmark problems for robotics research, (b) motivate and educate young researchers, and (c) make robotics research accessible to the general public.

The most prestigious of the FIRA competitions is the HuroCup competition for intelligent humanoid robots. Its focus is on providing challenges and benchmarks for humanoid robotics research, particularly active balancing and push recovery, complex motion planning, and human-robot interaction. The humanoid robots in the event must be fully autonomous. Moreover, a single humanoid robot must compete in a decathlon of archery, basketball, triple jump, marathon, obstacle run, Spartan race, sprint, united soccer, weightlifting, and mini-drc, see Fig. 2. A single humanoid robot is capable to perform a vast variety of tasks, which are relevant for humans, unlike, possibly more efficient special-purpose solution for a single task. For example, a wheeled robot can deliver mail in an office more cheaply and reliably. Similarly, a robot with suction cups is better able to clean windows. The teams are not allowed to modify their robot physically between events, as the creators of the competition believe that intelligence is the ability to adapt and adjust to many different tasks and environments, rather than solving a specific problem optimally. In fact, humans generally do not find the optimal solution but find satisfying solutions, that is, solutions that are good enough in practice. For example, when grocery shopping, people follow the store layout instead of solving the traveling salesman problem in their heads.

FIRA also includes HuroCup Jr., a subset of slightly simplified HuroCup event for U19 participants, where we used a similar approach to design the competition.

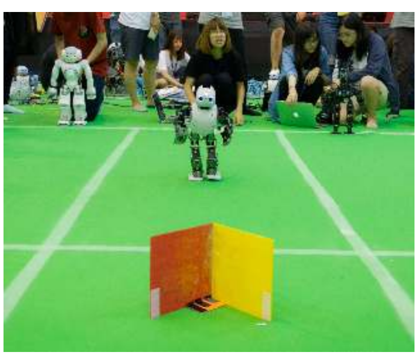
(a) Archery

(b) Basketball

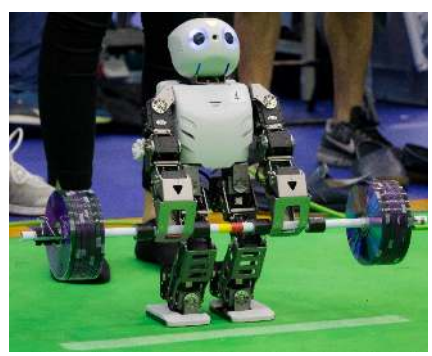


(c) Marathon

(d) Spartan race



(e) Sprint



(f) Weightlifting

Fig. 2: Events of the FIRA HuroCup archery, basketball, marathon, Spartan race, sprint, and weightlifting.

Rules of FIRA Youth - Mission Impossible The FIRA Youth - Mission Impossible is another competition targeted to younger participants that especially attempts to alleviate the problems of the commercial or parents-made hardware and software solutions discussed above. Here Students must implement a solution to a previously unknown task within 3 hours. FIRA Youth - Mission Impossible uses tasks in many different environments to avoid overspecialization. Sometimes, tasks are more focused on the hardware and mechanics of the device, such as a boat driven by rubber bands, whereas intelligent software is a priority at other times.

For the competition students bring their robot hardware and software. The maximum number of actuators (four continuous revolution motors with or without position feedback, six servo motors) and sensors (six IR sensors, four ultrasound, and four touch sensors) are described in the rules [5]. In addition, students are allowed to use commonly available materials (e.g., cardboard, Lego pieces, wood, and metal) and tools such as pliers, drills, and screwdrivers. For certain events, the rules may include additional restrictions. For example, students may only be allowed to use a maximum of one actuator (any type), and/or may only use a maximum of three light sensors and two ultrasound sensors. U14 students must solve simplified versions of the U19 challenges.

FIRA Youth - Mission Impossible United The challenges in the FIRA Youth - Mission Impossible United are such that multiple robots from different teams must synchronize and collaborate to achieve the goal; see Fig. 3. For the United competition students and their robots are partnered randomly with students from another country. A respective student team typically consists of four students from two different nationalities and two robots.

When introducing the FIRA Youth - Mission ImpossibleUnited event, many skeptics were concerned that the students' mother languages are different and that some of them cannot speak English, as a common language, well. Hence, all participants must provide a one-page introduction in English before being admitted to the FIRA Youth - Mission Impossible. In practice, we realized that students often manage even without English since the topic of discourse is robotics, which is expressed in mathematics or source code and students nowadays also use web-based translation.

Requesting collaboration during the competition fosters networking among the participants. Many friendships were forged in the late hours while trying to prepare the robot for the next day's competition. At the undergraduate and graduate student levels, many students were able to connect with their future supervisors. Our experience is that these friendships and exchanges are common for older students, but the connections are limited to members of the national teams in the U14 and U19 age groups.

Reception of FIRA Youth - Mission Impossible The FIRA Youth - Mission Impossiblecompetition has proven to be very popular with the FIRA Youth participants and is the largest and most prestigious FIRA Youth competition.

One of the surprising results of introducing the FIRA Mission Impossible was their reception by the teachers and educators. Occasionally there have been complaints, e.g. when teams had to tape over their extra light sensors in their sensor bars, thus making their standard software useless. However, we learned at many wrap-up meetings with teachers that many teachers really enjoyed preparing their teams. The teachers we interviewed explained that even though it is relatively easy to build a competitive entry for events where commercial solutions are available, creating a winning entry often requires optimizing the calibration of sensors and/or fine-tuning PID control loops to improve a run by a few microseconds. However, they much preferred teaching the scientific method, physics, mechanics, electronics, and real-time programming to sensor calibration and tuning control loops. As a positive aspect, teachers pointed out the possibility of introducing specific topics to their teaching, such as how the center of mass affects the balance, how to build a robot from scrap materials, and how to use a light sensor as a scanner since these may be chosen as the next FIRA Mission Impossible. Indeed, the FIRA Mission Impossible task in 2016 was to design a robot that could balance on a small horizontal rod. In 2017, the participants had to build a small boat that could raise a treasure, and in 2018, the challenge was to distinguish different images on a wall.

4 FIRA Youth - Mission Impossible 2021 - Bottle Weights

In 2021, the FIRA Robot WorldCup was organized as a virtual event, due to the COVID pandemic. The event was held and refereed simultaneously in several labs worldwide and coordinated on the FIRA Discord server[6]. Of course, most of the interaction and networking of the participants was limited to their local hub, but he virtual competition still motivated and excited students, especially since the teams still saw the other participants running their robot. In the future, we would try to organize several online sessions, which would allow students to mingle before and after the event.

Teams had to design and implement a robot that can estimate the weight of four bottles with 100 mL, 200 mL, 500 mL, and 1000 mL of water added. The bottles were attached to the robot via a rope and pulley system; see Fig. 3.

After announcing the rules of the competition, the teams discussed different methods for estimating the weight of the attached bottle. After a short while, they realized that the force acting on the robot could be estimated by controlling the power/torque settings of the motors (i.e., controlling the pulse width modulation (PWM) duty cycle of the DC motor) and then measuring the time that it takes the robot to drive across the lines marked on the table. It is important that the robot drives in a straight line to make the measurement reliable.

Some teams used the Lego analog motors, which control the velocity directly so that the robot moves at a selected velocity in spite of an external force applied

[6] https://discord.gg/QDpjK7Gfxe

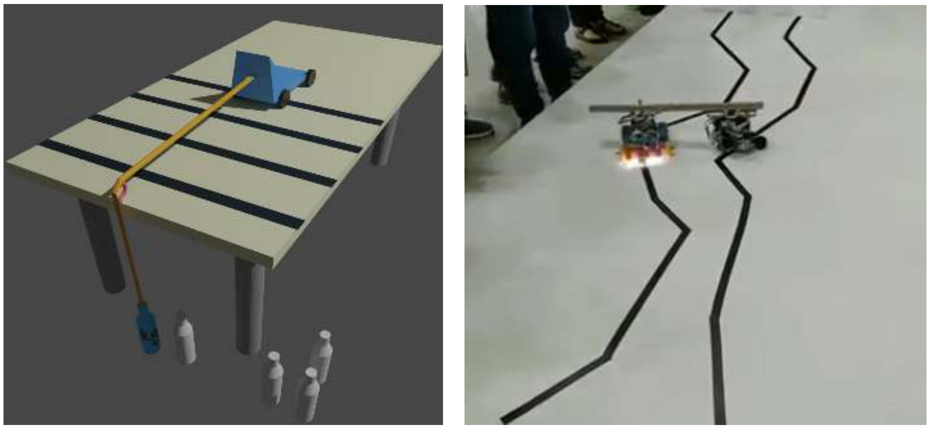


Fig. 3: The FIRA Youth - Mission Impossible 2021 competition required teams to estimate the weight of several bottles (left); the FIRA Youth - Mission Impossible United competition asked students from different countries to carry a beam (right).

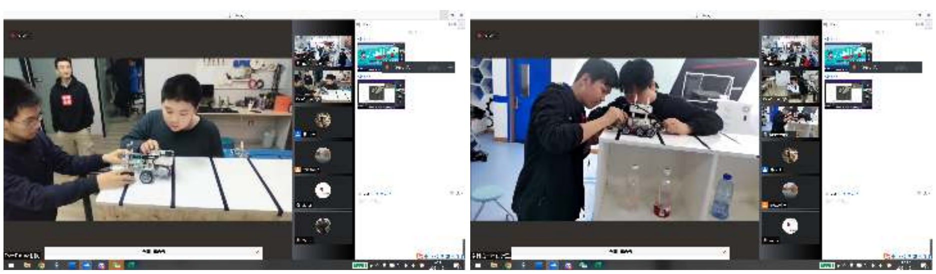


Fig. 4: Participants of the FIRA Youth - Mission Impossible 2021

to the robot. Some U19 teams worked around that problem by driving the robot forward across the lines and then by letting the bottle drag the robot backward. A snapshot from the competition is depicted in Fig. 4.

5 Wrench Estimation for Hexapod Robots

This section discusses an example of how robot competitions targeted at young students can provide important and meaningful inspiration for further research. A team of researchers at the Czech Technical University in Prague (CTU) is working on multi-legged walking robots and is experienced with intelligent robotics and developing impressive robots [1]. CTU-teams scored multiple times in the prestigious DARPA Subterranean (SubT) competition [2] or MBZIRC competition [12]. The main hexapod walking robots of the CTU team is the SCARAB II (left) and larger Lily robot (right) depicted in Fig. 5.

Fig. 5: CTU's SCARAB II (left) and the larger Lily robot (right).

The dynamics of multi-legged robots are difficult to model since they experience complex environmental interactions. Apart from the reaction forces of the feet touching the ground on several contact points, interactions due to uneven terrain, collisions with obstacles [11], or user interaction [19] occur. Most previous approaches model these interactions only implicitly [15, 18, 10] that is the control policy compensates for external disturbances.

However, explicit modeling of the external wrench opens new and interesting opportunities for intelligent robotics; since the robot can "sense" an obstacle that is outside of the view of its camera, it can solve "peg in hole" type of manipulation problems, maintaining tension on a tether or leash, or safe collaborative manipulation [14]. Hence, there is increased interest in explicit wrench estimation. For example, the authors of the survey [17] report on the increased interest in explicit wrench estimation, specifically during the DARPA Robotics Challenge. Wrench estimation is non-trivial since the dynamics are difficult to model due to the strong coupling of the robot base with legs and ground contacts [16].

In search of a suitable approach to develop and benchmark external wrench on legged robots, the researchers realized that the bottle weight mission is an easy test setup that can consistently apply a known torque without other significant impacts on the kinematics and dynamics. Thus, they created two test beds, one using a flat plane and one using an irregular surface, see Fig. 7 left and right. The test beds used a motion capture system to measure the exact position of the robot with an accuracy of one millimeter.

The exact method of the new wrench estimation is not within the scope of this paper will only be sketched shortly. The new approach for external wrench estimation is based on the formulation of the whole-body dynamic model of the robot used to derive the analytical formulation for the ground reaction forces and external wrench estimation, which are only forces and torques acting at known and unknown contact points of the robot, respectively, as it is shown in Fig. 6, and formulated in the following equation of the robot's rigid-body dynamics model.

$$\boldsymbol{M}\begin{bmatrix}\ddot{\boldsymbol{\mathcal{X}}}\\ \ddot{\boldsymbol{q}}\end{bmatrix}+\begin{bmatrix}\boldsymbol{\eta}_{\boldsymbol{\mathcal{X}}}\\ \boldsymbol{\eta}_{\boldsymbol{q}}\end{bmatrix}=\begin{bmatrix}\mathbf{0}\\ \boldsymbol{\tau}\end{bmatrix}+\sum_{i=1}^{N_l}\begin{bmatrix}\boldsymbol{J}_{\boldsymbol{\mathcal{X}}_i}^T\\ \boldsymbol{J}_{\boldsymbol{q}_i}^T\end{bmatrix}\begin{bmatrix}\boldsymbol{F}_{e_i}\\ \mathbf{0}\end{bmatrix}+\begin{bmatrix}\boldsymbol{\mathcal{F}}_{\mathrm{d}}\\ \mathbf{0}\end{bmatrix}, \tag{1}$$

where $\boldsymbol{\mathcal{X}} = [x, y, z, \theta_x, \theta_y, \theta_z]^T$ is the robot's position and orientation in the global reference frame, N_j is the number of robot's controllable degrees of

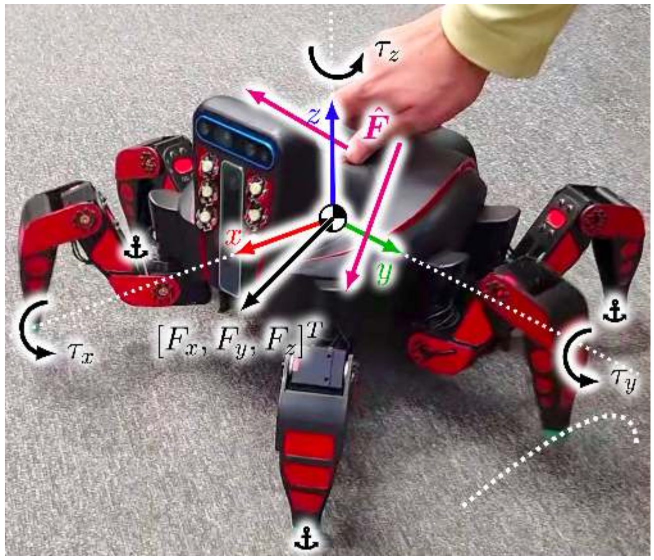


Fig. 6: Illustration of an external wrench acting on the six-legged walking robot SCARAB II in human-robot interaction and ground contact. The operator exerts external forces $\hat{\boldsymbol{F}}$ on the chassis of the robot that is in motion. The robot estimates the resulting wrench $\boldsymbol{\mathcal{F}}_{\mathrm{d}} = [F_x, F_y, F_z, \tau_x, \tau_y, \tau_z]^T$ w.r.t. its center of mass.

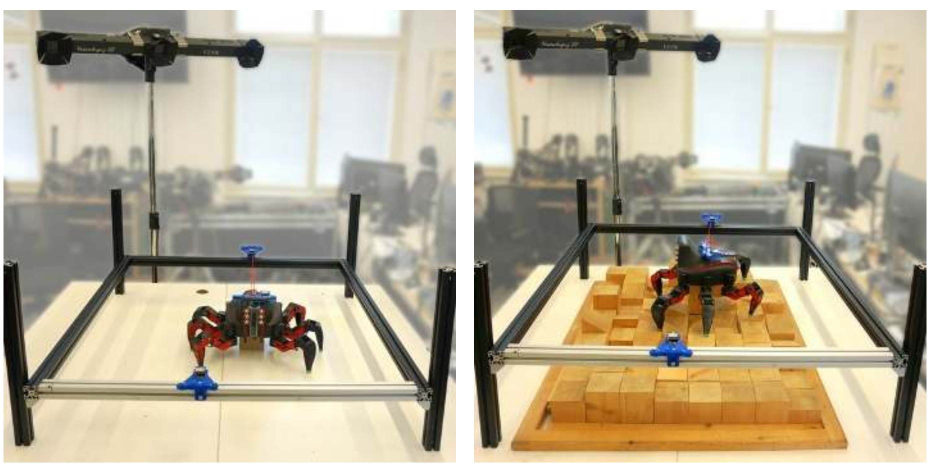


Fig. 7: The test bed for evaluation of the external wrench on a flat (left) and irregular terrain (right). The weight inducing a known external wrench on the robot is suspended on a cord attached to the robot. The position of the robot is tracked using a motion capture system.

freedom, $\boldsymbol{q} \in \mathbb{R}^{N_j}$ is the vector of the generalized joint coordinates, $\boldsymbol{M} \in \mathbb{R}^{N_j+6 \times N_j+6}$ is the system inertia matrix, $\boldsymbol{\eta}_{\boldsymbol{\mathcal{X}}} \in \mathbb{R}^6$ and $\boldsymbol{\eta}_{\boldsymbol{q}} \in \mathbb{R}^{N_j}$ are the joined Coriolis, centrifugal, and gravity effects of the body and joints, respectively. $\boldsymbol{\tau} \in \mathbb{R}^{N_j}$ is the motors torque, N_l is the number of robot's legs, $\boldsymbol{J}_{\boldsymbol{\mathcal{X}}_i} \in \mathbb{R}^{6\times 6}$ and $\boldsymbol{J}_{\boldsymbol{q}_i} \in \mathbb{R}^{6\times N_j}$ are the contact Jacobian with respect to (w.r.t.) the body and legs, respectively, $\boldsymbol{F}_{e_i} \in \mathbb{R}^3$ represents the individual ground reaction forces, and $\boldsymbol{\mathcal{F}}_{\mathrm{d}} \in \mathbb{R}^6$ is the cumulative external wrench acting on the robot body.

The example shows how robotics competitions can support lead to and support serious research.

6 Conclusions and Future Work

Robot competitions are a powerful tool for teachers to motivate students and evaluate their progress. However, in order to reach these goals organizers must be aware of some potentially problematic issues and design competitions well with a pedagogical concept in mind, as we detailed in this paper. Commercial interests and external ambitions can affect the learning outcomes of competitions, especially if the rules and environment of competitions remain the same with little changes and do not evolve. If competitions are designed such that students can prepare robots and software beforehand, changes during the competition ensure an appropriate involvement of the students. Teachers of participating teams confirmed ad-hoc changes to competitions as being positive, even though students need to be prepared for on-the-spot thinking and quick problem solving. Ad-hoc peer teams, like in FIRA Youth - Mission Impossible United fosters networking and collaboration.

A participant informed us that since about 20 % of the teams can solve the entire challenge, it is really not a mission *impossible*. It may be of great value to teach today's youth that solutions are, despite older people in authority trying to tell them that it cannot be done. We close with a famous quote by George Bernhard Shaw [4].

> "Reasonable people adapt themselves to the world. Unreasonable people attempt to adapt the world to themselves. All progress, therefore, depends on unreasonable people."

The FIRA Youth - Mission Impossible organizers and the rest of the FIRA community hope to inspire the unreasonable youth of today.

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