Analysis of Autonomous Robotic Competitions for Problem-Based Learning

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Abstract

Participation in autonomous robotic competitions can be a rewarding problem-based learning experience for students. The challenges involved in these competitions provide students with an opportunity to improve various technical and teamwork skills. Robotics competitions often necessitate collaboration between students of different STEM fields, such as computer science, electrical engineering, and mechanical engineering (and related). For autonomous robotics competitions, the mandatory autonomous nature of the robot further increases the need for programming and Computer Science skills in the design process.

This paper presents initial work on the characterization of the value of participation in autonomous robotic competition teams. The characterization focuses on analyzing the aspects of the competitions and the potential associated benefits from these aspects. The analyzed autonomous robot competitions include the Intelligent Ground Vehicle Competition (IGVC), RoboSub, International Aerial Robotics Competition (IARC), and the Student Unmanned Aerial Systems (SUAS) competition.

1. Introduction

Competitions and prizes can contribute to innovative changes by influencing society or specific communities and individuals. According to Dias et al. [1], the potential societal benefits of competitions include identifying excellence, influencing public perception for a specific domain, focusing communities on specific problems and mobilizing new talent, strengthening problem-solving communities by educating individuals.

This paper presents initial work on the characterization of the value of participation in autonomous robotic competition teams. The characterization focuses on analyzing the aspects of the competitions and the potential associated benefits from these aspects. The analyzed autonomous robot competitions include the Intelligent Ground Vehicle Competition (IGVC), RoboSub, International Aerial Robotics Competition (IARC), and the Student Unmanned Aerial Systems (SUAS) competition.

This paper is organized as follows. First, background information on research in robotics education and problem-based learning is discussed. Then, an overview of the selected autonomous robot competitions is presented. Third, the role that autonomy plays in these competitions in terms of programming involvement is detailed. Fourth, the estimated benefits to problem-based learning is discussed. This paper concludes with a summary of the paper and a discussion of future work.

2. Background

In this section, work in related topics are discussed. First, related work in robotics competitions and education is outlined. Then, the benefits of problem-based learning are analyzed.

2.1 Robotics Competitions and Education

For robotics education, Zdešar et al. [2] found that students typically appreciate a balance between theory and practice. In this regard, the use of competitions could provide an excellent means of practice, which could be augmented with theory through the aid of a competition mentor or advisor. Moreover, a study done in 2002 by Ahlgren and Verner [3] showed that robotic contests could lead to considerable progress in theoretical and practical areas for students, both at the K-12 and university levels.

The level of engagement and interest observed in students participating in robotics projects is also of note. Merkouris et al. [4] found that students were more engaged by programming robots than they were for programming applications for a desktop computer. Remote education and training are also possible through the simulation and programming of robots. An example of this is the Robotic Programming Network (RPN), which is an initiative that involves writing ROS code in an Internet browser and running it on a remote robot [5].

2.2 Problem based learning

According to Savery [6], problem based learning (PBL) is an instructional (and curricular) learner-centered approach that empowers learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem. In this approach, students have the responsibility for their own learning. In effect, this can provide an incentive for students to become more intrinsically motivated to learn, and potentially develop or enhance self-directed, lifelong learning skills [7]. Moreover, the problem is often an integration of a wide range of disciplines or subjects [6]. Thus, collaboration is essential, with students potentially becoming more effective collaborators as a result.

Robotics is an especially effective medium for problem-based learning for many reasons. According to Ahlgren et al. [8], these include: students become involved in self-directed learning, interdisciplinary design, teamwork, professional communication, technical invention, and research. Another reason is that intensive practice in solving diverse mental and physical tasks in the robotics medium can promote development of student intelligence and creativity [8].

3. Autonomous Robot Competitions

In this section, an overview of the selected autonomous robot competitions is presented. The analyzed autonomous robot competitions include the Intelligent Ground Vehicle Competition (IGVC), RoboSub, International Aerial Robotics Competition (IARC), and the Student Unmanned Aerial Systems (SUAS) competition.

COMPETITION	VEHICLE TYPE	# OF VEHICLES	SOFTWARE	ELECTRICAL	MECHANICAL
IGVC	Ground	1	● ● ●	● ●	● ● ●
ROBOSUB	Underwater	1-2	● ● ●	● ● ●	● ● ● ●
IARC	Aerial (In-door)	4	● ● ● ●	● ● ●	●
SUAS	Aerial (Outdoor)	1	● ●	● ●	● ●

Table 1: Overview of the vehicle type and estimated field difficulty of the discussed autonomous robotic competitions.

Table 1 provides an overview of the vehicle type, number of vehicles, and estimated difficulty of each field for the discussed competitions. The field difficulty estimates are based on experience competing, or designing vehicles with the intent to compete, in the discussed competitions. The estimates are meant to illustrate the variability from competition to competition and aren't intended to be used as a metric to rank the competitions. Furthermore, many of the tasks in these competitions are open ended; therefore, the difficulty may vary based on how ambitious a team's design is.

3.1 Intelligent Ground Vehicle Competition (IGVC)

In the Intelligent Ground Vehicle Competition (IGVC), a fully autonomous unmanned ground robotic vehicle must negotiate around an outdoor obstacle course under a prescribed time while maintaining a minimum of speed of one mph over a section and a maximum speed limit of five mph, remaining within the lane, and avoiding the obstacles on the course [9]. Obstacles on the course consist of various colors of construction barrels/drums that are used on roadways and highways. In addition, natural obstacles such as trees or shrubs and manmade obstacles such as light posts or street signs are also sometimes present on the course.

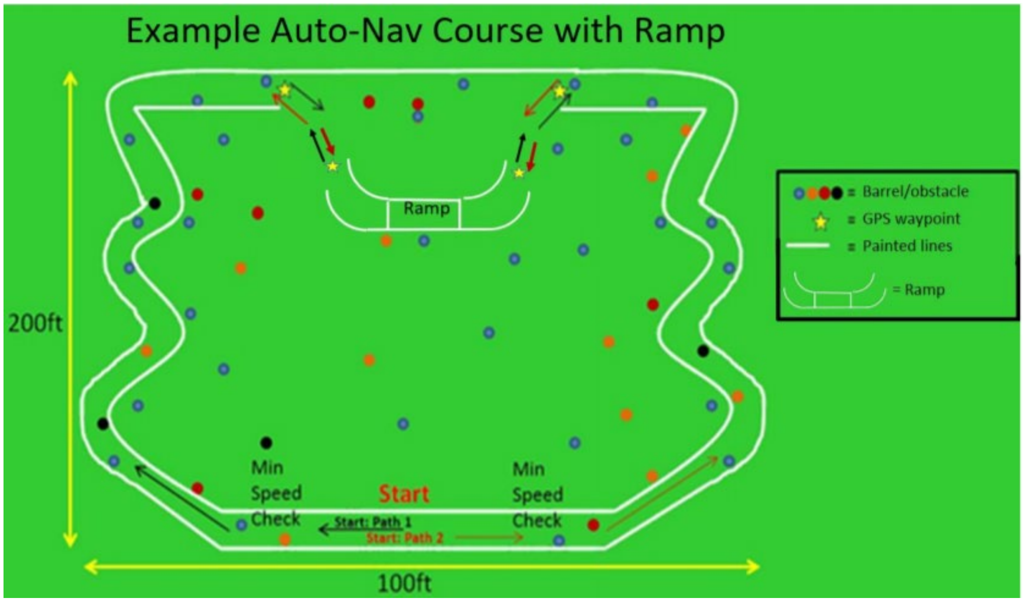

Figure 1: Example IGVC course layout [9].

The course, as depicted in Figure 1, is primarily sinusoidal curves with a series of repetitive barrel obstacles. Two waypoint pairs for the course are provided to the team prior to competition. One waypoint pair is the entrance and exit of the course in “No Man’s Land” (area in the center). There are two additional target/goal waypoints in “No-Man’s Land”.

3.2 RoboSub

The fundamental goal of the mission is for an autonomous underwater vehicle (AUV) to demonstrate its autonomy by completing various tasks [10]. Each vehicle must operate autonomously during its mission, with no communication permitted between the vehicle and any person or off-board computer. Therefore, the AUVs must operate solely on their ability to sense and maneuver in the arena using on-board resources. If more than one vehicle is desired, multiple vehicles (two total) are allowed in the competition. Inter-vehicle communication and cueing of one vehicle by another is an advanced behavior that merits special points. Although, the cost of building an AUV may deter teams from constructing more than one vehicle.

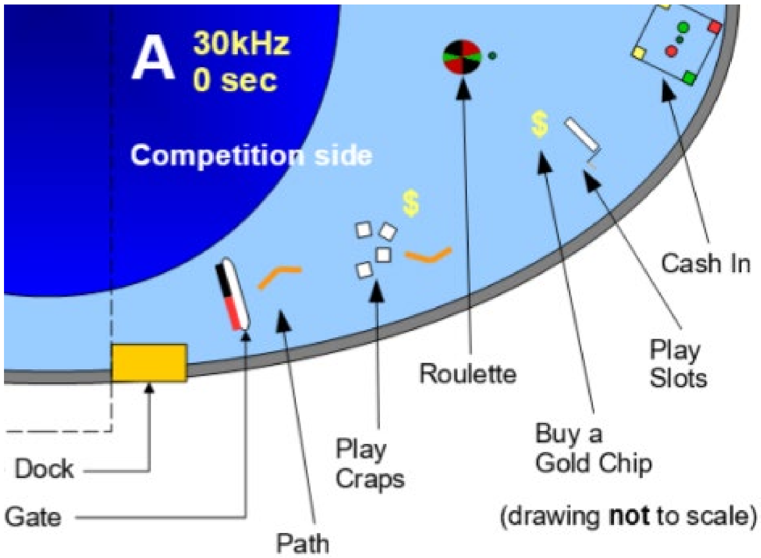

Figure 2: RoboSub course layout for the 2018 competition, which had a casino theme [10].

There is typically a theme to the competition, where the 2018 competition had a casino theme (depicted in Figure 2) and the 2017 competition had a "20,000 leagues under the sea" theme. The tasks are similar from year to year but vary in the details based on the theme. The tasks for the RoboSub competition include:

- *Pass through the gate*: This is the only required task of the competition, and more points are awarded if the vehicle enters backwards or does a barrel role while passing through the gate.
- *Touch Buoys*: In 2018, the narrative involved "Playing Craps" which had the buoys shaped like dice and more points were awarded if the total of the dice hit added to seven or eleven.
- *Drop object(s) into container(s) and/or acquire object(s) from container(s)*: In 2018, this involved dropping "chips" (golf balls) into an underwater roulette wheel prop.
- *Fire 'torpedoes' into openings*: The torpedoes used are small rods that are fired from small compressed air tanks. In 2018, the narrative involved pulling a lever on a slot machine and firing the torpedoes into a slot. In 2017, this involved firing torpedoes at a large cut out prop that looked like a giant squid.
- *Locating and Surfacing in designated area*: In 2018, the narrative involved surfacing with any collected "chips" (golf balls) in the designated area.

3.3 International Aerial Robotics Competition (IARC)

The International Aerial Robotics Competition (IARC) typically has missions that persist for more than one year primarily due to the associated difficulty involved. The current mission, mission 8, was introduced in 2018, and remains the mission for 2019. The objective for this mission is as follows: enter the Reactor Room and retrieve the four parts comprising the critical component and take it out of the Reactor Room through the doorway you entered without being 'killed' and do it in under 8 minutes [11]. This task is complicated due to the presence of "hostile sentry aerial robots," and is only possible using team designed helper robots.

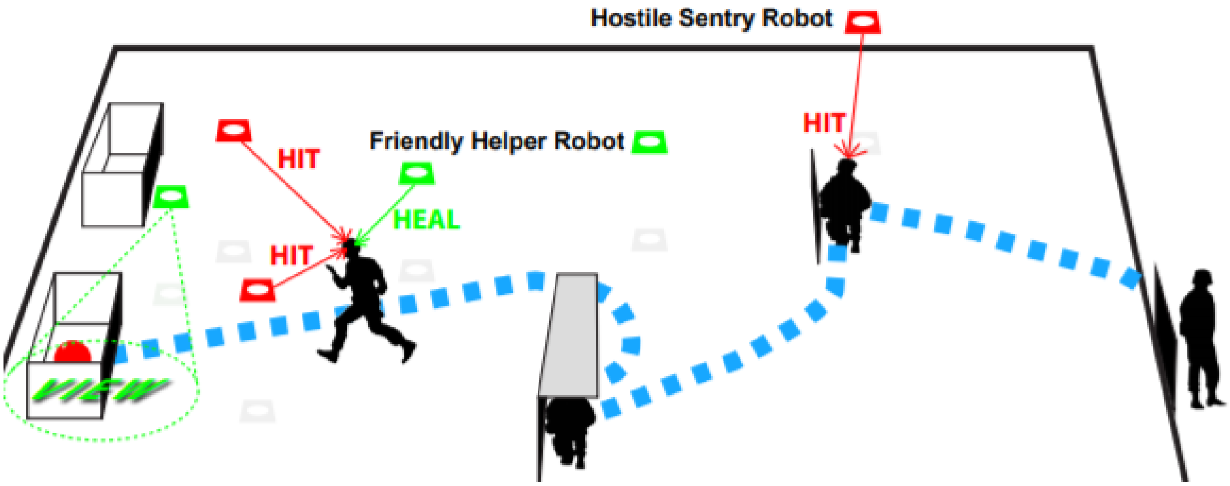

Figure 3: IARC mission 8 tasks and course layout [11].

To accomplish the mission, teams design four friendly aerial robotic helpers based on off-the-shelf platforms or original designs. In this regard, the estimated difficulty in Table 1 for the mechanical portion of this competition assumes primarily off-the-shelf platforms are used (although electrical modifications are often needed to accommodate the specific tasks). The aerial robotic helpers must fly fully autonomously, stay within the arena, avoid obstacles (including sentry robots), respond to verbal or gesture commands, and hold position over a storage bin on command. For operational efficiency, it is desirable that the 4 aerial robots be able to communicate electronically amongst themselves (although they aren't allowed to communicate electronically with the player or team). To aid the player, the aerial robotic helpers can heal laser hit wounds sustained by the person in the arena with a "surgical laser" (in reality, a harmless green light).

The hostile sentry aerial robots belong to the arena and are designed and operated by the arena staff. These aerial robots are autonomous, but at times use "directed autonomy" to keep them in the arena and within reasonable altitude bounds, should they wander. Sentry robots will attack the person in the arena with an offensive laser (in reality, a harmless red light), and will approach and follow the person until they can neutralize them with their laser beams.

3.4 Student Unmanned Aerial Systems (SUAS)

The Student Unmanned Aerial Systems (SUAS) competition is designed to foster interest in Unmanned Aerial Systems (UAS), stimulate interest in UAS technologies and careers, and to engage students in a challenging UAS mission [12]. The competition requires students to design, integrate, report on, and demonstrate a UAS capable of autonomous flight and navigation, remote sensing via onboard payload sensors, and execution of a specific set of tasks.

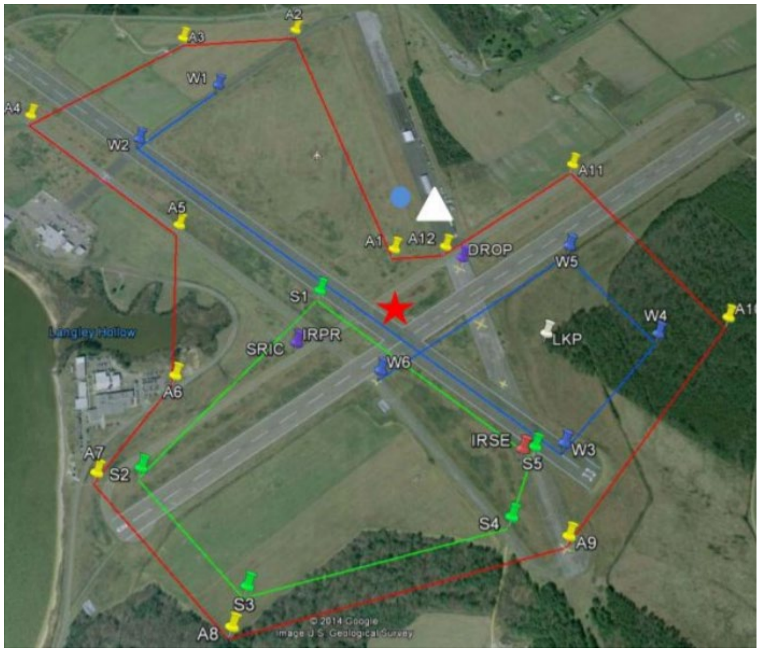

Figure 4: SUAS course overview [12].

The mission (depicted in Figure 4) consists of autonomous flight, obstacle avoidance, object detection, and air drop. The mission narrative is that a package delivery company has tasked an Unmanned Aerial System (UAS) to deliver a package to a customer. The UAS must avoid obstacles like buildings, identify potential drop locations, drop the package to a safe location, and then move the package to the customer's location. The team may use a single Unmanned Ground Vehicle (UGV) at the competition as part of the air drop task, which adds an element of multi-robot coordination.

4. Role of Autonomy

The presence of autonomy in robotics competitions may bring the involvement of programming to similar levels compared to the mechanical and electrical aspects. To illustrate this, Figure 5 shows a Venn diagram of many of the major contributions that each field would need to accomplish in order to build/program a robot. In this section, this notion is further explored with technology examples and task involvement.

One utility for programming robots is the Robot Operating System (ROS), which is a framework/environment to run robot(s). It is possible to develop ROS nodes in C++ or Python code, although there are a number of open-source packages available to use as well. The open-source packages allow users to setup their robot with certain basic or fundamental capabilities, without the need to do significant amounts of programing. These capabilities include processing sensor data, mapping, and localization. More importantly, it also has packages to allow teams to easily setup a robot to be teleoperated (controlled with a joystick or other control interface). Thus, if the software team is knowledgeable in how to use ROS, setting up a robot for a teleoperation task is reasonably quick and trivial. However, ROS does have a learning curve associated with it, so individuals new to it may have a sufficient amount of work for non-autonomous robotic competitions.

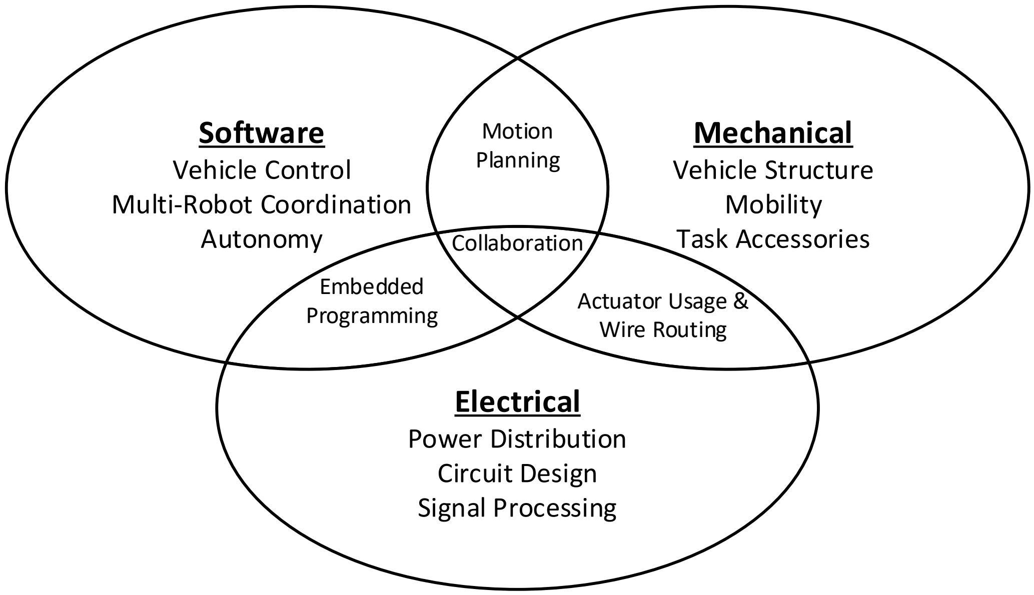

Figure 5: Venn diagram of robot design needs by field of study.

An example of a robotic competition which primarily involves teleoperation is the Marine Advanced Technology Education (MATE) competition. The MATE competition involves teams developing a remotely operated underwater vehicle (ROV), and can be viewed as a teleoperated version of RoboSub. There are certain autonomous tasks in the competition, primarily image processing related, but the difficulty of these tasks is low and are only potentially complicated by light refraction in water (which is more of a physics problem). However, the majority of the tasks involve teleoperation and may not present a challenge to more skilled programmers. Although, the mechanical and electrical aspects of the competition are fairly involved and could be characterized as challenging. Thus, the inclusion of additional autonomous tasks may help bridge this gap. However, not every competition is necessarily focused on the programming aspect, so it becomes the student's (or advisor's) job to find competitions that are appropriate for the team member's skill levels.

Competition	*Image Processing*	*Path Planning*	*Path Following*	*Sensor Fusion*	*Mapping*	*Task Planning*	*Human-Robot Interaction*	*Multi-Robot Coordination*
IGVC	● ● ●	● ● ●	● ● ●	● ●	● ● ●	●	-	-
RoboSub	● ● ● ●	● ●	● ●	● ● ●	● ●	● ● ●	-	● ●
IARC	● ● ●	● ● ●	● ●	● ●	● ●	● ● ●	● ● ●	● ● ● ●
SUAS	● ●	● ●	● ● ●	● ● ●	●	● ●	-	●

Table 2: Estimated level of autonomous activities in selected competitions.

Even amongst the discussed autonomous robot competitions, the associated software tasks and challenges vary in terms of difficulty and effort. Table 2 provides estimates of the levels of various autonomous activities in the discussed competitions. These estimates aren't meant to rank the competitions, but to illustrate the amount of work involved in designing the software for the robot(s), and how the work can vary from competition to competition. The categories are as follows:

- *Image Processing*: analyzing images in order to detect objects, shapes, lines, or other features of interest.
- *Path Planning*: system and algorithms that determine a suitable path to a given location. An example would be interfacing a larger system with an A* algorithm that uses an obstacle map.
- *Path Following*: system and algorithms that instruct the mobility hardware on how to follow a given path (e.g. pure pursuit, Stanley steering, etc.).
- *Sensor Fusion*: combining of sensor data from different sources such that the resulting information has less uncertainty (often used for position determination/localization).
- *Mapping*: use of senor data to form a map of local terrain or detected obstacles. The map could then be used for path planning and/or path following.
- *Task Planning*: system that determines how to perform a task or the order in which to perform a set of tasks.
- *Human-Robot Interaction*: verbal or non-verbal communication between a robot and human.
- *Multi-Robot Coordination*: interaction system that coordinates the behavior of multiple robots in order to accomplish an objective or objectives.

5. Student Benefits and Problem-Based Learning

Participation in autonomous robotic competitions can be a rewarding problem-based learning experience for students. The challenges involved in these competitions provide students with an opportunity to improve various technical and teamwork skills. Moreover, robotics competitions often necessitate collaboration between students of different STEM fields, such as computer science, electrical engineering, and mechanical engineering (and related). Since students from these different fields need to collaborate with one another to find a solution, valuable teamwork skills may be gained as a result. Furthermore, the need to coordinate these activities in the group may increase leadership skills and experience for the individuals in those roles.

These competitions can (in many instances) expose students to state of the art technology and potentially increase their chances of being hired in their desired field. For instance, an excerpt from the official purpose statement for the IGVC is as follows. "The IGVC offers a design experience that is at the very cutting edge of engineering education. It is multidisciplinary, theory-based, hands-on, team implemented, outcome assessed, and based on product realization. It encompasses the very latest technologies impacting industrial development and taps subjects of high interest to students [9]." Moreover, participating in a competition may itself be a good item for a student to include on their resume. In addition, the competitions also provide a venue where potential employers may be scouting for talent.

For computer science education, the inclusion of autonomy in robotics competitions may be a good way to encourage more advanced programming students to participate. One of the problem-based learning goals, intrinsic motivation, may be impacted if the problem is not inherently challenging to a student [7]. Thus, this becomes an issue of providing a skill-level appropriate challenge to students. Although, this may not be possible in all cases, as a group of students may decide to compete in a competition without first consulting a faculty advisor. In other cases, participation in a robotics competition could count towards research credit or a senior design project. In this case, it would be appropriate to identify which competition would be suitable for the field of study and challenging enough to justify the number of credits (without being overwhelming to students).

6. Conclusions and Future Work

This paper presented initial work on the characterization of the value of participation in autonomous robotic competition teams. The analyzed autonomous robot competitions included the Intelligent Ground Vehicle Competition (IGVC), RoboSub, International Aerial Robotics Competition (IARC), and the Student Unmanned Aerial Systems (SUAS) competition. An overview of these autonomous robot competitions was presented. The role that autonomy plays in those competitions was detailed. The estimated benefits to problem-based learning was discussed.

Future work is planned to further investigate the role of autonomy in robot competitions. In particular, a wider range of competitions will be discussed and potentially a survey will be used to infer the attitude students have toward the autonomous competition tasks.

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