# Analysis of Competitions for Mechatronic Design Using Autonomous Mobile Robots

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**Abstract**
There are many miniature robot-building competitions used in teaching mechatronics. Brigham Young University has historically used an autonomous miniature mobile robot competition as the basis for an upper-level mechatronics course. A new competition design was sought that satisfies specific criteria. The department-specified criteria include incorporating a balanced approach to teaching mechatronics fundamentals, providing inherent flexibility in difficulty level, scalability for varying student enrollment and future development, and increased student appeal. We evaluated 100 internet-sourced mechatronic mobile robot competitions using the defined criteria.

Analyses using these criteria allowed the identification of underlying principles employed in the exploration and teaching of mechatronics. We identified desirable educational and mechatronic outcomes for inclusion in the course. We then designed a new competition that meets all of the defined criteria. The new competition allows flexibility in development time requirements (ranging from one semester to multiple semesters) and provides options for many levels of difficulty. It was tailored to the new competition requirements by matching specific criteria to features and principles found in other competitions. The criteria, mechatronics teaching principles, and competition details are presented and discussed.

## Mechatronics Development at Brigham Young University

Teaching mechatronics offers some specific challenges. A student with a background in computing, electronics or mechanics is unlikely to be proficient in all three areas, yet mechatronics requires the successful integration of these three disciplines. The EET (Electronics Engineering Technology) department at Brigham Young University traditionally taught mechatronic principles to upper-level students. This course was designed for students with backgrounds in computing, electronics and/or mechanics. As part of the course requirements, each team of students was required to create and program an autonomous robot that would compete in a task-oriented competition at the end of the semester. The evolution of the EET department into the current Information Technology department offered the opportunity to design a new mechatronics course to meet new needs.

**Pedagogical Approach**
As noted earlier, the nature of mechatronics creates specific teaching challenges. The discipline is an integrative one rather than a narrowly defined specialty. Students tend to come into the class from different disciplines with strong backgrounds in one of computing, electronics or mechanisms but may be quite ignorant of the other disciplines. At BYU we have chosen to use the development of an autonomous miniature robot as the medium for teaching this diverse field. Students are strongly motivated by the experience of building a working unit and thus rapidly learn those sub-disciplines in which they are lacking. Since students must define their own solution to the problem they will similarly define their own course of study.

The pedagogical approach is to ensure that the class covers the fundamentals in each of the related fields and that the design assignment will almost certainly require the students to explore each of the fields of computers, electronics and mechanisms in creating their solutions[2]. Miniature robots accomplish this second goal very successfully. The class also must guide the students to understand the principles of mechatronics, to enable them to conceive of solutions that can be implemented in more than one technology and then to evaluate the available technologies to select the best solution.

**Methods of Instruction**
In setting up class at BYU we have pursued this objective of self-directed learning. As indicated above, the class can be considered to consist of three major components. The first is ensuring that all students are at least minimally conversant in all three sub-disciplines. This is accomplished by lectures and fairly traditional lab experiences where the students explore the various sub-systems. Lab experiences are differentiated. Students with mechanical backgrounds complete labs with an electronic emphasis and vice-versa. The second consists of class discussion and reading in the field of mechatronics, where students gain an insight into the possibilities of multiple technological solutions and the power inherent in selecting the most effective design[5].

The third class component consists of the project. Students are presented with a problem to solve and then design and build suitable miniature robots to accomplish the goal according to measurable criteria. Undoubtedly this is the most popular part of the class for the students and that motivation leads them to self-learning[4]. Other outcomes of the class include teamwork, project management, and written and oral communication. Overall we have found this class to be very successful in both introducing students to mechatronics, and in helping them develop their own learning skills.

**Defining Project Criteria**
This paper will focus on the third part of the class components, the team project. It was necessary to define what specific needs must be met to design an effective robot competition[1]. A careful consideration of department goals and student needs resulted in a list of desirable attributes for any new robot competition. These are the "Competition Analysis Parameters" we used to study several existing competitions. The criteria and method of analysis in the analysis data tables (appendix, Tables 1 through 3) are explained below.

## Competition Analysis Parameters

### Mechatronic Balance – 33/33/33% Goal

Since Mechatronics is an integrative discipline the course and competition analyses look for an a balanced emphasis on the three major disciplines, namely:

1. Computer/Software programming
2. Electronic sensors, actuators, and circuit integration
3. Mechanical systems.

Ideally each of the three areas should represent ⅓ of the total mechatronics design. This allocation represents a rough estimate of the desired proficiency level for each discipline[5].

### Explore Mechatronic Issues

Many different types of robotics and autonomous competitions exist, each with different areas of interest. It was important to discover what mechatronics issues each type of competition explores in order to gather ideas and identify the most common components in each setting.

We reviewed competitions based on both technical and administrative criteria. The following criteria were developed to identify the presence of desirable sub-systems:

### Technical Evaluation Criteria

- Locomotion – Varied mechanisms used for transporting the robot from one location to another.
- Identification – The technology used to identify objects (infrared, ultrasonic, vision, etc.)
- Sensors – What sensors are used, how are they employed?
- Actuators – What actuators are required for the robot to compete in the competition (lights, LCD printouts, motors etc.)
- Positioning Systems – What technologies are used for navigation (shared vision, mini GPS, ultrasound, etc.)
- Teamwork & Communication – Is teamwork required between robots? What is the medium for team communication (infrared, 802.11b, etc.)
- Artificial Intelligence – Does the environment lend itself to an Artificial Intelligence situation?

### Educational and Administrative Evaluation Criteria

### Scope

The educational setting mandates these projects be completed in a reasonable amount of time. One semester is the most desirable time frame for a team of students to complete the competition. Extension to two semesters is possible but requires teams to commit to less flexible schedules, and limits the course as offered only once during an academic year rather than at least twice.

**Reasonable cost**
The competition must fit within a small budget for the students and within a reasonable budget for the college. By offering the same or similar competitions each year we can allow students to "cannibalize" components from past years' competition entries. This reduces overall cost and development time.

The college budget should also be considered. Reusing main components from each robot helps but does not cover all replacement costs. Most reusable parts will consist of motors, the development platform, the computer system, peripheral boards, motor drivers, etc. Another expense specific to the college is the competition arena. The college is sponsoring the class and sponsors the competition. The computer module and development environment for each robot is provided by the college and costs roughly $500 - $800 US dollars.

**Room for Creativity/Alternate Designs**
An opportunity to solve the competition with a variety of solutions is important. It is desirable to explore many options for the same problem and to allow students to succeed in such an environment. A competition that can only be completed by a rolling robot of a specific size, shape, and design is not desirable. A competition that would allow walking, rolling, jumping, sliding, stationary robots, etc. would be a much more desirable competition. This is given a rating of 0 to 10 with 10 as most flexible.

**Student Appeal**
Admittedly, it is desirable to have a competition that is entertaining to watch and appealing to those participating. The premise of the competition or arena should inspire a desire to watch or participate[4]. This is ranked 0 to 10 with 10 as highest appeal.

**Suitability for College**
The competition should be appropriate for an upper-level college course and require substantial discipline and knowledge of the topic. The two columns for rating these criteria are challenge and interest. Challenge is ranked from 0 to 10 with 10 as the most challenging. Interest is ranked in the same manner. Challenge expresses the level of difficulty for a competition and if it is appropriate for an upper-level college course. Interest expresses the level of appeal that the given competition would generate among college students.

**Competition Time**
How a winner is selected and what the style of the competition is. (For example, a race for the best time, or rounds of elimination by performance, etc.)

**Style of Competition**
How is the competition conducted? It may be task-oriented, head-to-head, designed for an individual robot, or multiple robots working as a team. An example of task-oriented competition is to find a burning candle in a maze, blow it out and then retrieve it from the maze. An example

of head-to-head competition is two robots in a maze racing to find the burning candle first. A team competition would have multiple robots per team with two or more teams competing to find and retrieve the candle first. Flexibility and scalability are important considerations to allow for fluctuating enrollment.

## Competition Analysis

### Approach

We began by comparing over 100 robot competitions that had sites on the Internet. We selected fifty competitions that came closest to meeting our criteria for analysis. A panel of three BYU students analyzed these remaining fifty mechatronics competitions according to the criteria enumerated above[3]. It might be noted that such student involvement provided the desired student perspective on topics such as student appeal. Each of the competition comparisons is detailed in the tables of the appendix, while general results are discussed below.

### Results

Comparison between competitions and criteria showed general trends in the survey samples (Figure 1). A relatively uniform integration of disciplines is partially due to how we selected the analyzed competitions. The "balance" of mechatronics issues was slightly skewed to favor the mechanics of robots (Figure 1). This is due, in part, to competitions like "N.W Robot Sumo Tournament" (Table 1, entry 4) that required no software programming, leaving the major development emphasis on mechanics. Such competitions were mainly considered on the merits of their mechanical aspects as viable elements in a new competition. Electronics showed the least amount of emphasis in the autonomous competitions we selected. These competitions involved robots with minimal electronics and sensors, relying instead on programming and computational abilities to perform the desired tasks. There were, however, competitions such as "Walker" and "Atomic Hockey" (Table 1, entries 29 and 30) that demonstrated a desirable balance between the three mechatronics disciplines.

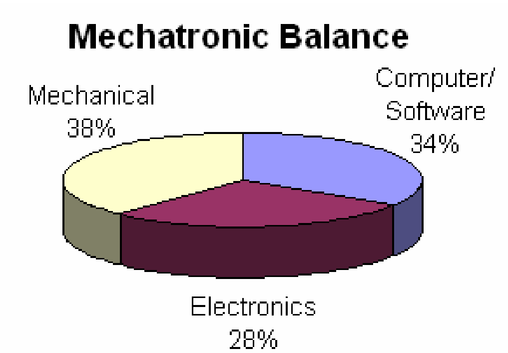


**Figure 1: Overall allocation of disciplinary emphasis for the analyzed competitions.**

The analysis also revealed what types of competitions are most popular, (i.e., what works). We found that the majority of the competitions are based on teams of people with individual robots that compete against time or each other (Figure 2). This is most likely due to the increased complexity associated with engineering teams of cooperative robots. Just over half of the competitions were task oriented, meaning there was a predefined objective and minimal interaction with the environment. This also indicates that many competitions have successfully employed schemas that require "real-time" autonomous decision-making.

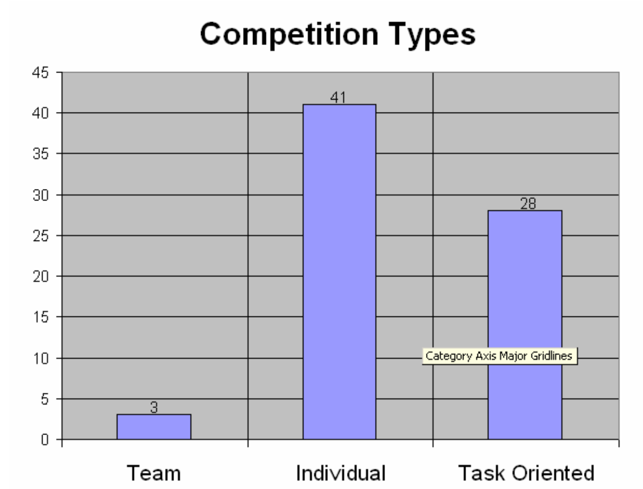


**Figure 2: Makeup of analyzed competition types—Competitive teams of cooperative robots, competitive individual (one-on-one) robots, or task oriented competitions for single robot entries.**

Among the more subjective analysis criteria were "Student Appeal" and "Challenge". The analysis showed that, on average, a *participant* would find the competitions more appealing than would a casual *observer*. On a rating of 1-10 the competitions' "appeal" averaged 4.78 for the observer and 5.49 for the participant, comprised of competition score ratings over the entire range of 1 to 10 (see Table 2, entries 32 and 40 respectively). The engineering challenge presented by the arena and rules of play was also rated between 1 and 10. The average for all the competitions was 5.38, with individual competitions scoring over the entire range of 1 to 10 (see Table 2, entries 13 and 2 respectively). This represents a mix of both challenging and non-challenging competitions in the analysis with varying degrees of appeal, and demonstrates room for improvement in the majority of existing competitions. Such improvements were made in our new competition by designing an adaptable "challenge" level, specifically with "appeal factors" in mind.

## The New Competition

We developed a new competition to meet the criteria set forth above. The competition is designed to be flexible in that some aspects could be omitted to simplify the class while still encompassing all the desired mechatronic principles in an engaging way. The following is an example of a new competition that meets the criteria set forth above. It was designed using the analysis results as guidelines. The arena consists of a 12' x 8' plywood base with a suspended second-story level that overhangs approximately half of the floor's surface area. The second level is accessible by two gentle-sloped side ramps and one (steeper) center ramp. Play may occur with or without navigating the second level, although incentives may be found to do so. The two-level arena provides added challenge and enhances appeal for both spectator and participant. The scale of the arena is large enough to accommodate multiple robots at once, while

*Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition*

the dimensions of the overhanging level impose a physical limitation that encourages novel solutions.

The competition rules were tested by a group of students who simulated a dummy competition using all rules for play and scoring. This process allowed the identification of potential design inadequacies and rule loopholes. Analysis of the simulated play led to several modifications in the competition rules and scoring system, which were incorporated into the current design.

Rules of the competition and robot guidelines are found below. Any or all of the devices and aspects of the arena may be employed, in any combination, to adjust the challenge level of the competition. The arena goals and devices will be connected to a central computer that will track points and time information for scoring purposes. Relevant information will also be available from that computer to the robots via a wireless signal.

**Purpose**
The object of the game is to collect the most points possible within a set time limit. Several methods for acquiring points are available to each autonomous robot.

**Objects**
The main task is to find and retrieve objects on the playing field. The robot must then identify the object and return it to the goal for point increase. The goal has two different drop locations. Sorting the objects correctly will maximize scoring value. An alternative is to discard the object for no points or to drop it in the "vacuum" to deduct points from the opponent's score. Storing objects is acceptable and encouraged, however points are only awarded when the objects are successfully returned to the goal.

**Task Buttons**
Another task of the competition is to find and actuate a button. Two buttons exist and each team is assigned to one button. The Blue button will add points to the blue team and disable the scoring mechanism for the white team for a period of time. The White button will add points to the white team and disable the scoring mechanism for the blue team for a period of time. Pushing the wrong button will disable your team and give points to the other team.

**Special Challenges**
Several different advanced challenges have been planned. Collection of objects from these challenging locations will earn extra points. Some of the challenges could include retrieving an object from a platform, climbing stairs to retrieve and object, etc.

**Multiplier**
If this object is dropped into your goal it would act as a multiplier on every object dropped in your goal thereafter. Example: A "multiply by 2" is dropped into the goal. An object normally worth 10 points is now worth 20 points when it is dropped into the goal. The multiplier remains active from the time it is dropped into the goal until the end of play.

**Doubler**
If this object is dropped into your goal it will double your current score. Therefore you will want to have points on your scoreboard before you drop this device into the goal. This object is only active at the instant it is dropped into the goal.

**The Score Board and Timer**
A visual display will show (to the spectators and participants) the score of each team and the remaining playing time. The robots will also have this information available via a wireless signal. When the time expires the robots must stop. There is a penalty for continued play after time expires.

**The Goals**
Each goal will have two "drop locations". Sorting the objects into the correct drop location will maximize points. Failure to sort objects correctly will yield half of the point value. For example if object *A* is dropped into location *A* it is worth 10 points, however if it is dropped into location *B* it is only worth 5 points. An object dropped into an opponent's goal will count toward that opponent's total.

**The Vacuum**
The vacuum is a mechanism designed to deduct points from the other team. This is an option to consider if you would like to take away points from the other team instead of traveling to your goal to achieve points. Consider the time it takes to deposit an object into your goal versus dropping the object into the vacuum. Each time the vacuum is used by either team, the point deduction value will increase for the next use. The exact deduction value will be available over a wireless signal.

**Variable Point Values**
The points for each object will fluctuate throughout the game. The playing field will transmit a signal indicating the percentage of the point value for awarded each object at that instant. This value will fluctuate as a function of time throughout the play of the game. The method for value change will be assigned to a periodic waveform and controlled by the arena computer. Therefore the value could oscillate with a sinusoidal characteristic, follow a ramping pattern, or even follow a repeating pseudo-random pattern. It is the task of the competitors to strategize and evaluate this variable to determine the best time to deposit objects into the goal for maximum points. The object would be assigned the value at the time it is deposited. This offers a timing strategy for placing objects in the correct location at the correct time. It is not required to detect the variable point value.

**Scoring Points**
Scoring points is accomplished in several ways. Robot construction is scored. Robot speed and size are scored. The competition also rewards the abilities and execution of the robot.

**Minimum Competition Requirements**

The robot must be able to maneuver from point *A* to point *B* in the competition arena. Object retrieval is not a minimum requirement. Detection of the outside boundary is required. The robot must support its own weight; no part of the object can be dragged except by design and with prior approval. For example wires, sensors, chassis, motors, etc. cannot touch the ground during any part of the competition.

The following areas earn points:

Ingenious Mobility: Extra points for non-wheeled machines.
Robot Construction: The judge will rate the quality of construction.
Smallest Robot: This is the robot with the smallest footprint area as viewed from above.
Largest carrying capacity: This is the robot that can carry the most competition objects at one time.

The following events will cause a loss of points:

Assisting/Touching the robot during play
Opponent drops object into the Vacuum
Unresponsive to disable signal
Out of bounds
Robot Falling from a ramp or upper level

**Judging**

The final score determination will be made by the judges; any discrepancies will be settled by the judges. The judges will determine if a robot is unfit prior to the competition. If the robot does not meet the minimum requirement, it is unfit to participate in the competition.

Three independent judges will be assigned to score robots on creativity, construction quality, largest carrying capacity, and smallest robot. These scores will be on a 0 to 100 scale with 100 be the highest score.

**Conclusions**

We have historically used an autonomous miniature mobile robot competition as the basis for an upper-level mechatronics course in the Information Technology department at Brigham Young University. Designing a new competition for a redesigned course required enumerating specific criteria to meet. The department-specified criteria include incorporating a balanced approach to teaching mechatronics fundamentals, providing inherent flexibility in difficulty level, scalability for varying student enrollment and future development, and increased student appeal.

We identified the pedagogical requirements of the course as well as logistical constraints, which we used as the basis for screening and analyzing 100 internet-sourced mechatronic mobile robot competitions. We identified useful trends after screening those competitions for elements that fit our criteria. We then utilized those criteria-meeting elements in formulating a new competition that meets our needs. We were able to effectively synthesize a new competition by selecting relevant elements from a pool of existing, prescreened competitions.

The new competition allows flexibility in development time requirements (ranging from one semester to multiple semesters) and provides options for many levels of difficulty. It was tailored to the new competition requirements by matching specific criteria to features and principles found in other competitions. The competition track is currently under evaluation by a team of students.

## Appendix

| | | Mechatronic Balance | | | Mechatronic Issues | | | | | | | Reasonable cost | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | % | | | Y/N | | | | | | | Student | College | |
| Number | Name | Computer/ Software | Electronics | Mechanical | Locomotion | Identification | Sensors | Actuators | Positioning systems | Teamwork-communication | Artificial Intelligence | Use of past projects | Reusable Parts | Competition arena |
| 1 | MicroMouse | 50 | 30 | 20 | ? | Y | Y | Y | N | N | N | Y | Y | ? |
| 2 | MicroSot | 80 | 10 | 10 | Y | Y | Y | Y | Y | Y | Y | Y | Y | |
| 3 | N.E. Indiana Robot Games | 30 | 20 | 50 | Y | Y | Y | Y | N | N | N | Y | Y | Y |
| 4 | N.W Robot Sumo Tournament | | 40 | 60 | Y | N | N | Y | N | N | N | Y | Y | Y |
| 5 | The OCAD Sumo Robot | 40 | 20 | 40 | Y | Y | Y | Y | N | N | N | Y | Y | Y |
| 6 | RoboCup | 80 | 10 | 10 | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| 7 | RoboDeminer | 55 | 15 | 30 | Y | Y | Y | N | Y | N | N | Y | Y | Y |
| 8 | RoboFlag | 40 | 30 | 30 | Y | Y | Y | Y | N | Y | N | Y | Y | Y |
| 9 | Quick Trip (RoboRama) | 60 | 30 | 10 | Y | N | Y | N | N | N | N | Y | Y | Y |
| 10 | Line Following (RoboRama) | 55 | 35 | 10 | Y | Y | Y | N | N | N | N | Y | Y | Y |
| 11 | T-Time (RoboRama) | 60 | 30 | 10 | Y | Y | Y | N | N | N | N | Y | Y | Y |
| 12 | Can Can (RoboRama) | 30 | 35 | 35 | Y | Y | Y | Y | N | N | N | Y | Y | Y |
| 13 | RobotBattles | | 20 | 80 | Y | N | N | Y | N | N | N | Y | Y | Y |
| 14 | Robot Conflict | | 20 | 80 | Y | N | N | Y | N | N | N | Y | Y | Y |
| 15 | Robot Riots | | 20 | 80 | Y | N | N | Y | N | N | N | Y | Y | Y |
| 16 | The Line Slalom (Rob. Games) | 70 | 15 | 15 | Y | N | Y | N | N | N | N | Y | Y | Y |
| 17 | Hexapod Challenge (Rob. Games) | 20 | 30 | 50 | Y | N | N | Y | N | N | N | Y | Y | Y |
| 18 | Lego Mindstorms (Rob. Games) | 20 | 20 | 60 | Y | N | Y | Y | N | N | N | Y | Y | Y |
| 19 | Maze Challenge (Rob. Games) | 40 | 45 | 15 | Y | Y | Y | N | N | N | N | Y | Y | Y |
| 20 | Trinity LEGO Cybernetics Chall. | 30 | 30 | 40 | Y | Y | Y | Y | N | N | N | Y | Y | Y |
| 21 | Twin Cities Mech War | | 25 | 75 | Y | N | N | Y | N | N | N | N | N | N |
| 22 | USA Robot Sumo | | 20 | 80 | Y | Y | Y | Y | N | N | N | Y | Y | Y |
| 23 | Underwater Robotics Competition | 35 | 15 | 50 | Y | Y | Y | Y | Y | N | ? | Y | Y | N |
| 24 | Walking Machine Challenge | 40 | 30 | 30 | Y | Y | Y | Y | Y | N | Y | Y | Y | Y |
| 25 | Robot Sumo (W Can R. Games) | 20 | 40 | 40 | Y | Y | Y | Y | N | N | N | Y | Y | Y |
| 26 | Mini Sumo (W Can R. Games) | 20 | 40 | 40 | Y | Y | Y | Y | N | N | N | Y | Y | Y |
| 27 | BEAM (W Can R. Games) | 45 | 45 | 10 | Y | Y | Y | Y | Y | N | Y | Y | Y | Y |
| 28 | Robo Innovation (W Can R. Games) | ? | ? | ? | ? | ? | ? | ? | ? | ? | ? | N | N | N |
| 29 | Walker (W Can R. Games) | 33.3 | 33.3 | 33.3 | Y | ? | Y | Y | N | N | ? | Y | Y | Y |
| 30 | Atomic Hockey (W Can R. Games) | 33.3 | 33.3 | 33.3 | Y | Y | Y | Y | Y | N | Y | Y | Y | Y |
| 31 | Extinguisher (W Can R. Games) | 75 | 10 | 15 | Y | Y | Y | Y | P | N | N | Y | Y | Y |
| 32 | Line Follower | 80 | 10 | 10 | Y | N | Y | Y | N | N | N | Y | Y | N |
| 33 | MIT 2.007 | 10 | 30 | 60 | Y | N | Y | Y | N | N | N | Y | Y | Y |
| 34 | AAAI-2002 Mobile Robot Comp. | 55 | 30 | 15 | Y | Y | Y | Y | Y | Y | Y | Y | Y | Y |
| 35 | Robotrace Mice | 15 | 50 | 35 | Y | N | Y | Y | N | N | Y | Y | Y | Y |
| 36 | Micromouse | 35 | 30 | 35 | Y | N | Y | Y | N | N | Y | Y | Y | Y |
| 37 | Microclipper Mice | 20 | 40 | 40 | Y | Y | Y | Y | N | N | Y | Y | Y | Y |
| 38 | Sumo Wrestling | 20 | 29 | 51 | Y | N | Y | Y | N | N | Y | Y | Y | Y |
| 39 | Balloon Collection | 30 | 35 | 35 | Y | N | Y | Y | Y | N | Y | Y | Y | Y |
| 40 | BattleBots (the show) | | 30 | 70 | Y | N | N | Y | N | N | N | Y | Y | N |
| 41 | Mini Sumo Bots | 25 | 25 | 50 | Y | N | Y | Y | N | N | Y | Y | Y | Y |
| 42 | Robot Line Following Slolom | 25 | 35 | 40 | Y | N | Y | Y | N | N | Y | Y | Y | Y |
| 43 | Mobot Slalom | 25 | 40 | 35 | Y | N | Y | Y | N | N | Y | Y | Y | Y |
| 44 | Mobo Joust | 10 | 20 | 70 | Y | N | Y | Y | Y | N | Y | Y | Y | Y |
| 45 | Robot Soccer | 35 | 30 | 35 | Y | N | Y | Y | Y | N | Y | Y | Y | Y |
| 46 | Robot Vacuming | 40 | 30 | 30 | Y | Y | Y | N | N | N | N | Y | Y | Y |
| 47 | line Maze (robothon) | 60 | 30 | 10 | Y | Y | Y | N | N | N | N | Y | Y | Y |
| 48 | Floor Exercise (robothon) | ? | ? | ? | Y | ? | ? | Y | ? | N | ? | N | N | Y |
| 49 | BotBall | 50 | 10 | 40 | Y | Y | Y | Y | N | N | N | Y | Y | Y |
| 50 | Line Fetch | 40 | 35 | 25 | Y | Y | Y | Y | N | N | N | Y | Y | Y |

**Table 1: Analysis Data**

| | Scope Y/N | | | Student Appeal 1 to 10 | | Suitability for College rank 1 to 10 | | Type Rounds/Race | Style Y/N | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | Finishing in one semester | Open Competition | Room for Creativity Altemitive Design | Observer | Participant | Challenge | Interest | Elimination rounds or race | Team Oriented | Individual one on one | Task Oriented |
| 1 | Y | Y | Y | 5 | 6 | 8 | 5 | race | N | Y | N |
| 2 | | N | Y | 6 | 8 | 10 | 6 | Timed | Y | N | N |
| 3 | Y | Y | N | 4 | 5 | 5 | 4 | Rounds/Timed | N | Y | N |
| 4 | Y | Y | N | 6 | 5 | 4 | 3 | Rounds | N | Y | N |
| 5 | Y | Y | N | 4 | 5 | 5 | 4 | Rounds | N | Y | N |
| 6 | N | Y | Y | 6 | 8 | 10 | 5 | Game | Y | N | N |
| 7 | N | Y | N | 2 | 4 | 8 | 3 | Find Mines | N | Y | Y |
| 8 | N | Y | Y | 6 | 8 | 9 | 7 | Rounds | Y | Y | Y |
| 9 | Y | Y | N | 2 | 2 | 2 | 2 | Timed | N | Y | N |
| 10 | Y | Y | N | 3 | 3 | 3 | 2 | Timed | N | Y | N |
| 11 | Y | Y | N | 2 | 2 | 2 | 2 | Timed | N | Y | N |
| 12 | Y | Y | Y | 5 | 7 | 7 | 7 | Timed | N | Y | Y |
| 13 | Y | Y | Y | 7 | 3 | 1 | 2 | Rounds | N | Y | N |
| 14 | Y | Y | Y | 7 | 3 | 1 | 2 | Rounds | N | Y | N |
| 15 | Y | Y | N | 7 | 4 | 1 | 2 | Timed Rounds | N | Y | N |
| 16 | Y | Y | N | 3 | 4 | 2 | 3 | Timed | N | Y | Y |
| 17 | Y | Y | Y | 3 | 5 | 4 | 4 | Race | N | Y | Y |
| 18 | Y | Y | Y | 4 | 3 | 4 | 4 | Race | N | Y | Y |
| 19 | Y | Y | N | 3 | 5 | 6 | 5 | Timed | N | Y | Y |
| 20 | Y | Y | Y | 3 | 3 | 3 | 3 | Unspecified | N | Y | N |
| 21 | Y | Y | Y | 9 | 9 | 5 | 5 | rounds or race | N | Y | N |
| 22 | Y | Y | ? | 6 | 6 | 4 | 3 | head to head | N | Y | N |
| 23 | Y | Y | Y | 4 | 7 | 9 | 9 | Timed | N | Y | Y |
| 24 | ? | Y | Y | 5 | 8 | 10 | 8 | NA | N | Y | Y |
| 25 | Y | Y | Y | 3 | 5 | 5 | 5 | fastest | N | Y | Y |
| 26 | Y | Y | Y | 3 | 5 | 5 | 5 | fastest | N | Y | Y |
| 27 | Y | Y | Y | 5 | 6 | 7 | 7 | 5 minutes | N | Y | N |
| 28 | Y | Y | Y | varies | varies | 3 | 3 | judged | N | Y | ? |
| 29 | ? | Y | N | 4 | 8 | 10 | 8 | timed | N | Y | Y |
| 30 | Y | Y | Y | 6 | 6 | 8 | 9 | 3 minutes | N | Y | Y |
| 31 | Y | Y | Y | 3 | 4 | 4 | 2 | timed | N | Y | Y |
| 32 | Y | Y | N | 1 | 3 | 2 | 2 | NA | N | Y | Y |
| 33 | Y | Y | Y | 5 | 6 | 6 | 6 | 45sec/round | N | Y | Y |
| 34 | N | Y | Y | 6 | 8 | 10 | 10 | until done | N | N | Y |
| 35 | Y | Y | Y | 4 | 5 | 5 | 6 | race | N | N | Y |
| 36 | Y | Y | Y | 5 | 6 | 7 | 7 | 10min rounds | N | N | Y |
| 37 | Y | Y | Y | 6 | 6 | 8 | 7 | 10min rounds | N | N | Y |
| 38 | Y | Y | Y | 6 | 5 | 5 | 4 | Timed Rounds | N | Y | N |
| 39 | Y | Y | Y | 7 | 7 | 8 | 8 | timed | N | ? | Y |
| 40 | Y | Y | Y | 10 | 10 | 6 | 10 | rounds | N | Y | N |
| 41 | Y | Y | Y | 7 | 7 | 7 | 7 | rounds | N | Y | N |
| 42 | Y | Y | Y | 5 | 5 | 5 | 5 | race | N | N | Y |
| 43 | Y | Y | Y | 6 | 6 | 6 | 6 | race, tasks | N | N | Y |
| 44 | Y | Y | Y | 5 | 5 | 5 | 5 | race | N | Y | N |
| 45 | Y | N | Y | 8 | 8 | 7 | 7 | rounds | N | Y | Y |
| 46 | Y | Y | N | 3 | 5 | 6 | 5 | timed rounds | N | Y | Y |
| 47 | Y | Y | N | 4 | 5 | 2 | 3 | race | N | Y | Y |
| 48 | ? | Y | Y | 5 | 5 | 1 | 2 | judged | N | Y | N |
| 49 | Y | Y | N | 3 | 6 | 5 | 5 | rounds | N | Y | Y |
| 50 | Y | Y | N | 2 | 4 | 3 | 3 | race | N | Y | Y |

**Table 2: Analysis Data**

| | |
|---|---|
| 1 | http://www.ece.ucdavis.edu/umouse/ |
| 2 | http://www.fira.net/ |
| 3 | http://www.geocities.com/CapeCanaveral/Launchpad/8735/ |
| 4 | http://www.sinerobotics.com/sumo/ |
| 5 | http://www.student.ocad.on.ca/info/sumo/ |
| 6 | http://www.robocup.org/02.html |
| 7 | http://www.rdc2002.com/ |
| 8 | http://roboflag.carleton.ca/ |
| 9 | http://www.dprg.org/competitions/index.html |
| 10 | http://www.dprg.org/competitions/index.html |
| 11 | http://www.dprg.org/competitions/index.html |
| 12 | http://www.dprg.org/competitions/index.html |
| 13 | http://www.scenic-city.com/robot/ |
| 14 | http://robotconflict.com/index.htm |
| 15 | http://www.robotrumbles.com/ |
| 16 | http://www.robots.org/2001_Robot_Games.htm |
| 17 | http://www.robots.org/2001_Robot_Games.htm |
| 18 | http://www.robots.org/2001_Robot_Games.htm |
| 19 | http://www.robots.org/2001_Robot_Games.htm |
| 20 | http://www.cs.tcd.ie/research_groups/cvrg/lego/index.html |
| 21 | http://www.tcmechwars.com |
| 22 | http://www.chibashoten.com/robot/ |
| 23 | http://www.auvsi.org/competitions/water.cfm |
| 24 | http://www.sae.org/students/walking.htm |
| 25 | http://www.robotgames.com/ |
| 26 | http://www.robotgames.com/ |
| 27 | http://www.robotgames.com/ |
| 28 | http://www.robotgames.com/ |
| 29 | http://www.robotgames.com/ |
| 30 | http://www.robotgames.com/ |
| 31 | http://www.robotgames.com/ |
| 32 | http://www.chibots.org/ |
| 33 | http://pergatory.mit.edu/2.007/ |
| 34 | http://www.cs.uml.edu/aaairobot/ |
| 35 | http://www.bekknet.ad.jp/~ntf/mouse/taikai/23rule-rt.html |
| 36 | http://www.bekknet.ad.jp/~ntf/mouse/taikai/23rule-mm.html |
| 37 | http://www.bekknet.ad.jp/~ntf/mouse/taikai/23rule-cl.html |
| 38 | http://www.fsi.co.jp/sumo-e |
| 39 | http://dc.cen.uiuc.edu/ |
| 40 | http://www.battlebots.com/ |
| 41 | http://www.robotgames.com/Event_Rules/2002-minisumo.htm (http://www.robotgames.com/) |
| 42 | http://kipr.org/robotmaze/index.html |
| 43 | http://www-2.cs.cmu.edu/~mobot/mobot.shtml (http://www.canadafirst.org/) |
| 44 | http://www-2.cs.cmu.edu/~mobot/moboj.shtml |
| 45 | http://users.rcn.com/ljstier/rules.html |
| 46 | http://www.botlanta.org/Rally/vac_rules.html |
| 47 | http://www.seattlerobotics.org/robothon/maze.html |
| 48 | http://www.seattlerobotics.org/robothon/maze.html |
| 49 | http://www.botball.org/ |
| 50 | http://whophlungpoo.com/rssc/ |

**Table 3: Analysis Data**

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