Comparing Two Grade 6-12 Robotics Programs: Botball vs. VEX VRC
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Robotics programs and competitions provide opportunities for people of all ages to learn about STEM as well as apply and improve skills in a hands-on manner. In the K-12 education system, these programs can allow students to develop those STEM skills further than what could be achieved with only a class. The competitive nature can also motivate students to put in more effort. Multiple such competitions exist at the K-12 level, and schools generally cannot support involvement in more than one or two. In this paper, Botball will be compared with VEX VRC, the two programs that the author has competed in. Both require that students apply mechanical engineering and computer science for the construction and control of competition robots, though they vary in how much focus each discipline receives.

1. Fundamental Game Differences

I. *Botball* has 2-minute fully-autonomous rounds with three **Seeding** runs, a **Double Elimination** tournament, and a **Documentation** score (each accounts for ⅓ of a team's overall score). Seeding rounds involve only one team on the field (allowed to use both sides), attempting to get the highest score they can. Double Elimination rounds involve two teams, with the higher-scoring side winning the round. Teams that are eliminated early in the DE tournament can compete in the **Alliance** competition, which is essentially Seeding with two teams working together. Alliance performance does not influence overall score. Documentation is based on an absolute scale with a scoring rubric and consists of 3 periods (submitted online and only for regional events) and an onsite presentation which include robot design and programming as well as team information. Qualifying for the highest-tier event (GCER) only requires that a team has attended a regional event. Teams generally build two robots. The field is 8'x8'[12]. The season begins in January and ends in July, with teams going to a maximum of two events (Regional and GCER).

II. *VEX VRC* has 2-minute, semi-autonomous rounds (15-second autonomous period, 105-second driver control period) for the **main competition** with randomized qualification matches and a Single Elimination tournament (as of the 2018-2019 season). The **Robot Skills Challenge** is a separate, optional competition (somewhat similar to Botball's Seeding) in which one team gets the entire field. The Skills Challenge is separated into two categories: Driver and Programming, each run being 1-minute long. The number of Skills attempts varies from event to event (3 attempts at Worlds 2019). Driver Skills has the robot controlled by a human and Programming Skills is fully-autonomous. Teams can also optionally keep an **Engineering Notebook** in which they record the development of their robot and team organization. The main competition has 4 teams per round, with two for each alliance (Red or Blue). Teams can only build one robot. Qualifying for the highest-tier event (Worlds) requires that a team performs well in their state competition (which they also have to qualify for), or that the team provides an Online Challenge submission and is chosen. Possible Worlds-qualifying awards at state competitions are:

- Tournament Champion (given to the two teams on the winning alliance)
- Tournament Finalist
- Tournament Semi-Finalist
- Skills Challenge Champion
- HS (High School) Excellence (the "highest award," given to teams that "[exemplify] overall excellence in building a high quality robotics program."[18] Given to teams that perform well and have good Engineering Notebooks)
- MS (Middle School) Excellence
- Design (given to the team with the best Engineering Notebook, decided by official VRC judges)
- Amaze

Each state is allowed to qualify a certain amount of teams so some awards do not always qualify for Worlds. For example, the 2019 Oklahoma State Championship gave 5 teams Worlds-qualifying awards (note that HS and MS teams competed for one Excellence award) :

- (2) Tournament Champions
- (1) Skills Challenge Champion

- (1) Excellence
- (1) Design

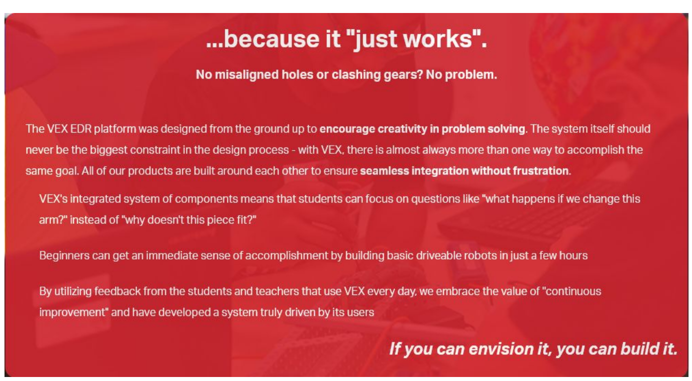
The field is 12’x12’[8]. The season begins in April and is all-year-round with next year’s game being announced near the end of Worlds. Teams usually go to several pre-state qualifiers, some qualify for the state championship, and a smaller fraction of those qualify for Worlds.

The fully-autonomous rounds of Botball have been used in marketing, with a slogan being “Real Robots Don’t Need Remote Control.” Anecdotally, some students have stated that this makes Botball more challenging than VRC. The fundamental game differences themselves do not point to either competition being more challenging or a better experience overall for the students involved.

2. Robot Mechanical Construction

Appendix A and B provide a general overview of parts and materials available to teams of each competition. The full parts lists for each competition are referenced in the appendices.

An extremely important difference between Botball and VRC exists at the mechanical level: VRC uses VEX EDR where everything is designed with the same hole spacing and overall system in mind, while Botball parts span three different hole spacing systems: LEGO, RC servo, and IGUS slide. VEX Robotics claims that “the VEX EDR platform was designed from the ground up to encourage creativity in problem solving.” They provide further justification for the standardized system on their “Why VEX EDR?” webpage:

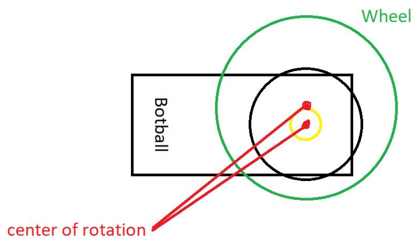


[20]

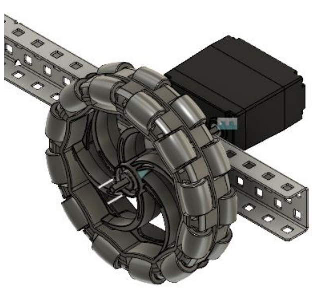
KIPR states that Botball's hole system variance is "by design to encourage innovative engineering solutions in the program."[19]

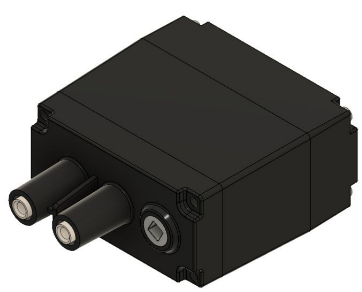
As an example, securely mounting a motor to any structural component allowed within the Botball parts list (excluding the Chassis, which is not very versatile) requires either use of an adapter or several Technic pieces going to different attachment points. In contrast, VEX motors and their standard hole spacing means a motor can be securely mounted directly to any VEX structural component using only two screws.

Another consequence of the use of RC servos is that mounting any wheel other than the Solarbotics wheels (which go directly on the servo horns) is more complex and less reliable than with VEX EDR. For example, mounting of a Technic wheel to a servo is usually done using three screws going into a servo horn at an angle. If they are not perfectly aligned, the wheel becomes non-concentric with the servo horn, causing eccentric movement.



VEX motors have female square hole outputs that accommodate the standard ⅛" shaft size (and ¼" high strength shaft size on the new V5 motors). As a result, any shafts attached to the motors are concentric and wheels on those shafts are concentric to the motor output as well.





This standard hole spacing also means that creating gear trains is less complex as well. Botball gear trains always involve adapting LEGO hole spacing to RC servo horn hole spacing, which has the same concentricity problems mentioned above.

VRC also allows for components to be cut and bent. Combined with the unlimited parts list, this allows for more complex designs than Botball.

VEX EDR has fewer different types of screws, causing less confusion.

As for whether misalignment is beneficial to students, KIPR's claims directly oppose VEX Robotics's: Botball's concentricity problems are "by design,"[19] while VEX Robotics states its intention is to "ensure seamless integration without frustration."[20]

Anecdote: Multiple Norman Advanced Robotics members believe that Botball's parts limit is beneficial as it is an analog to constraints that exist in real world engineering, while being forced to create solutions using incompatible parts was frustrating and unrealistic.

3. Robot Sensors

I. *Botball* has the following external sensors:

- "ET" (infrared distance)
- "Tophat" - large and small size (infrared reflectivity for line following)
- Light
- Linear slide
- Bump switches: large and small buttons, lever
- USB webcam

Internal sensors:

- Motor:
    - Back EMF (rotation detection through voltage generated by coil movement)
- iRobot Create 2
    - Cliff (infrared reflectivity for line following and cliff detection)
    - Infrared distance
    - Motor rotation (unknown method)
    - Bumper bar (left and right switches)

- Microcontroller
    - Gyroscope, 3-axis
    - Accelerometer, 3-axis
    - Magnetometer, 3-axis

II. *VEX EDR* has the following external sensors:

- Sonar (ultrasonic distance)
- Line (infrared reflectivity)
- Light
- Potentiometer
- Bump switches: button and lever
- Quadrature encoder (optical rotation detection with a perforated wheel)
- Gyroscope, 1-axis
- Accelerometer, 3-axis
- V5 Vision Sensor (high-performance object-tracking camera)

Internal sensors:

- V5 Smart Motor:
    - Quadrature encoder
    - Temperature
    - Torque and power calculated from current

Botball has a few small sensor advantages compared to VEX EDR. VEX EDR lacks a magnetometer entirely (but the magnetometer is extremely unreliable due to interference—ferrous metal objects near the microcontroller will change the output) and the infrared distance sensors in Botball can run much higher refresh rates than the sonar sensor (but have shorter range). The Botball gyroscope has 3 axes. Multiple single-axis VEX gyroscopes can be used but this would occupy more ports on the VEX microcontroller.

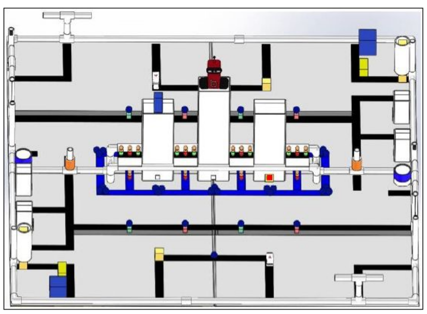
VEX EDR's quadrature encoders are more reliable to use than Botball's back EMF because one rotation of the perforated wheel outputs the same value every time while ticks from back EMF vary depending on how consistent the motor manufacturing is and how accurate the microcontroller voltage measurement is.

The potentiometer allows for precise, absolute rotation measurement of effectors that are driven by geared-down motors. This is simply impossible in Botball, with the closest solution being back EMF which is relative based on where the effector is when the program starts.

The V5 Vision Sensor runs at 640x400 resolution with a maximum refresh rate of 50 frames per second. Botball currently only supports "LOW_RES" (160x120) use of the Logitech webcam included in the kit, at an unknown maximum refresh rate.

4. Game Complexity

Botball's 2019 season:



[12]

13 unique game pieces:

Water cube, Botguy, mayor, medical supplies, food, firetruck, firefighter, ambulance, injured person, uninjured person, water pom, gas valve, electrical line

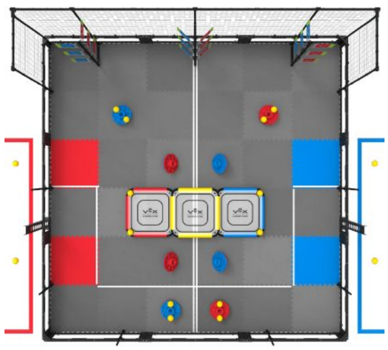
10 unique scoring zones:

Side, disaster relief zone, utility zone, water reclamation unit, fire station, burning skyscraper, sky bridges adjacent to burning, flood zone around burning, burning medical center, non-burning medical center

Some randomized game piece placement

2 robots per team

VEX VRC's 2018-2019 season:



[8]

4 unique game pieces:

Flag, cap, ball, robot

6 unique scoring zones:

Floor, low flag, high flag, post, alliance platform, center platform

No randomized game piece placement

1 robot per team

Botball is more challenging when comparing game complexity. It has more game elements and possible scoring paths. There is more focus on students brainstorming and optimizing their strategies compared to main competition VRC, where there is also strategy development but to a lesser extent. Botball teams must consider more unique game elements than VRC teams. High-performing main competition VRC teams spend large amounts of time practicing driving, which does not involve as much critical thinking as designing robot tasks and paths. However, VRC's Programming Skills Challenge actually matches or even exceeds Botball when considering movement complexity within a single robot. The highest scoring Programming Skills robot executed 51 movements (straight-drive, arc, or turn)[23]. The highest scoring Botball robot (from last season) had 41 movements in double the time (2 minutes vs. 1 minute)[24].

5. User-friendliness: Field construction

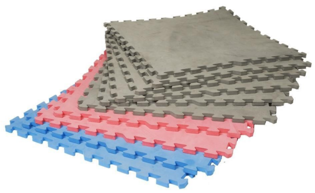
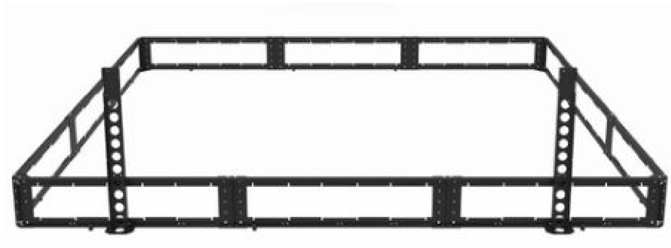
Field construction is one of the most significant frustrations that Botball teams seem to have. At the very beginning of the process, two 4'x8' wooden boards are needed as a foundation. Many vehicles cannot fit these. After placing those, there is the tedious process of aligning the (4) 4'x4' FRP panels to each other and the center divider.

This process only has to be done once but is frustrating to teams nonetheless.

Then, the PVC needs to be cut. This is a critical part of the process. If dimensions are not correct, the field will be different than competition fields and the robots will not work. A mitre saw is required for accurate cuts. After this, the PVC must be hammered together properly. There is no visual indication as to when lengths of pipe are fully hammered in. Once the PVC framework is assembled, it must be aligned with the divider, which is another tedious process. Corrugated plastic has to be cut for this year's field, which is also tedious and requires very sharp blades. Placing tape and game objects is the final process and is less tedious and dangerous. All of these field materials (besides the game pieces) must be obtained from local hardware stores. Hours were spent finding the specified products.

Despite the frustrations, the field design has the advantage of being low cost: two 4x8' MDF boards and two 4x8' FRP panels cost about $125 combined, and this foundation is reusable. Buying all of the PVC, tape, corrugated plastic, and other miscellaneous items for this year's field cost another ~$125.

VEX VRC's field construction begins with interlocking 2x2' foam tiles. These will fit in most automobiles. These tiles align themselves so teams only have to spend time placing them. The field perimeter is then assembled around the tiles. Screws hold the sections of the perimeter together so it is evident when it is properly assembled. Alignment with the tiles is simple as the perimeter can be shifted by lifting an edge.

[13] [7]

Game structures are attached to the field perimeter with machine screws or with plates that sit under the foam tiles. No drilling or cutting is required at all for assembly of the field. Taping and placing game objects is similar to Botball in difficulty (not very). All of these materials can be ordered from the official VEX website, so a few minutes at most is spent getting the needed parts for the field.

A consequence of the more specialized materials is higher cost: the foam tiles are $230[6] and the field perimeter is $800[7] (these are reusable). The game element set is $500[8]. Teams can make lower-cost plywood and PVC versions of the perimeter—official plans are available from VEX[25].

When assembling the fields, VRC is much safer and less frustrating for the students involved and/or less work for adult sponsors. Razor blades and mitre saws are not required for the full-cost VEX build.

6. User-friendliness: Microcontroller and IDE(s)

Botball's newest microcontroller is the Wallaby.

[11]

It has:

- (4) motor ports
- (4) servo ports
- (10) digital sensor ports
- (6) analog sensor ports
- (2) USB type-A ports
- (1) USB micro-B port
- Color touchscreen

The Wallaby takes a minimum of one minute to boot and turn on the wireless network for compiling programs. Wireless compiling (using KIPR IDE) has a maximum range in excess of 10 feet but is heavily affected by physical obstructions such as wires, structural parts, and/or field elements. It involves connecting to a WiFi network hosted by the Wallaby and has the advantage of working on any computer with a web browser, but it prevents that computer from accessing the internet. Wired compiling is done with a Ethernet-over-USB connection which often requires tweaking of drivers on computers. Wired compiling also takes longer than wireless. There is no limit to how many programs can be stored on the Wallaby.

VEX EDR's newest microcontroller is the V5 Brain.

[2]

It has:

- (21) "Smart Ports" for motors, sensors, Vision Sensors, and a Robot Radio
- (8) 3-wire legacy ports for digital or analog sensors
- (1) USB micro-B port
- (1) microSD slot
- Color touchscreen

The V5 Brain boots and is ready to compile to in less than 5 seconds. IDEs are available for Windows and MacOS. They require a program to be installed, unlike Botball. Wireless compiling (using VEXcode) has been reliable at distances of over 10 feet, through metal parts. It uses the V5 Controller's VEXnet connection to the Brain instead of a hosted WiFi network, so the computer can stay connected to the internet. Wired compiling is significantly faster. The V5 Brain stores up to 8 programs.

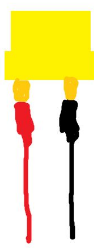
7. User-friendliness: Kit Durability

This section will cover incidents and causes of kit durability problems from each competition. Note that the VEX V5 system has only been released for a year; though fundamental design differences can still be analyzed.

The batteries used in Botball are 2-cell LiFePo4 6.6V 2000mAh batteries with XT-60 (the yellow plug) and JST-XH connectors.

[1] [4]

The JST-XH connector is used to charge the battery. The battery connects to the Wallaby using the XT60 connector. In Norman Advanced Robotics, there have been multiple instances of breakages in either connector. This is mostly due to user error, but the design can be improved by having connectors attached rigidly to the battery and Wallaby, with a standalone cable (or multiple). The heat shrink tubing can fall off of the joints and expose live contacts. The voltage is low so humans won't be electrocuted, but a short can destroy the battery and heat up an object enough to burn skin. When JST-XH connectors break, the batteries cannot be charged. The advantages of the standalone cable design are described in the section below.



VEX V5 batteries are 3-cell LiFePo4 12.8V 1000mAh batteries with a proprietary power connector and a DC 5.5x2.1mm barrel jack for charging.

[21] [22]

This is a fundamentally more durable design since no cables are directly attached to the battery or microcontroller. If the cable breaks, it is easy to replace it. The cable is also not susceptible to the heat shrink tubing issue as it appears to be crimped. Soldering needs to be done to repair Botball batteries and Wallabies if a connector breaks. The V5 motors and Robot Radio also have detachable cables.

Shockwave had three VEX gyroscopes break this season. The suspected cause was static electricity from the foam field tiles. After spraying the field with ACL Staticide Heavy Duty, no more gyroscopes failed. Over the course of 3 years, Norman Advanced Robotics has not had a single gyroscope failure. The Botball field does not include foam tiles so static electricity is a non-issue.

8. User-friendliness: Online Information

Botball has a Scores website that is supposed to keep a record of all regional tournament and GCER round scores for the current season. Access to game documents is only available to registered teams on the “Homebase.” The website crashes most mobile device browsers when users attempt to open the PDF game files.

VEX VRC competitions are all documented on https://www.robotevents.com . Full scoring records exist for tournaments as far back as 2012. Game documents are available to the public[5] and accessing the PDF files on a mobile device does not crash the browser.

9. Student Participation

VRC has over 11000 teams[3] while Botball has over 400 teams. In VRC, adults are not allowed to drive the robot or talk to referees.

Botball has an explicit rule against adults in the pits, and states that it is a "100% student driven experience." This is a massively important rule to have, which VRC game manuals lack. Anecdotally, coaches hovering over student shoulders in the pit and instructing them what to do has been seen multiple times at various VEX competitions. Sometimes, coaches were seen directly programming the robot. The Spirit of Botball prevents this and is definitely valuable in improving the student experience.

10. Cost

Botball:

New teams register for $2500 and are given the full kit of parts and game pieces for that year. Returning teams pay $1550 minimum per year, which includes the game pieces, sensors, motors, servos, and "select KIPR metal parts"[10].

The regional event is free for registered teams, while GCER registration is $110 per person. Note that GCER is considered a conference by KIPR and has guest speakers, presentations, and officially organized social events, which VEX Worlds lacks.

Initial cost for a Botball field is about $250 (explained in further detail in section 5).

VEX VRC:

Registration every year is $150 for the first team of an organization. Additional teams with different suffixes are $100 each[9]. For example, four Moore Norman Robotics "Shockwave" teams competed: 1742A, 1742B, 1742C, and 1742D.

There are multiple pre-state qualifier competitions, most of which were $80 to register a team for (in Oklahoma). The past two Oklahoma state championships have cost $150 to register for. VEX Worlds 2019 cost $975 to register for. The V5 Competition Super Kit costs $1500[3] but does not include critical sensors like potentiometers or a gyroscope. The initial full-cost configuration price for a VRC field is $1530 (section 5).

10 Year Cumulative Cost Analysis

This analysis assumes that:

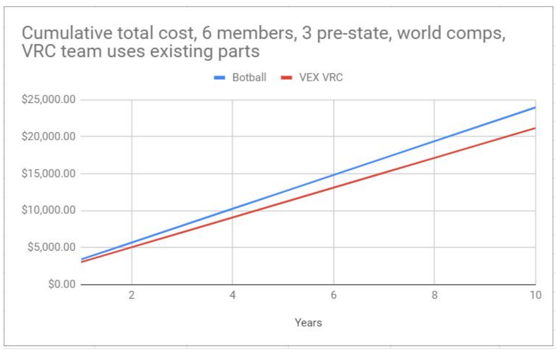
- Both teams have 5 students and 1 sponsor
- Both teams go to their highest-tier events (GCER and Worlds)
- The VRC team goes to 3 local pre-state qualifiers
- The VRC team spends another $500 on parts not included in the V5 Competition Super Kit

Initial Registration	GCER Registration	Field Cost	Botball	Year	VEX VRC	Initial Registration	Local Comp. Reg.	State Champ. Reg.	Worlds Reg.	Field Cost	Parts Cost
$2,500.00	$660.00	$250.00	**$3,410.00**	1	**$5,045.00**	$150.00	$240.00	$150.00	$975.00	$1,530.00	$2,000.00
$1,550.00	$660.00	$125.00	**$5,745.00**	2	**$7,060.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$8,080.00**	3	**$9,075.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$10,415.00**	4	**$11,090.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$12,750.00**	5	**$13,105.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$15,085.00**	6	**$15,120.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$17,420.00**	7	**$17,135.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$19,755.00**	8	**$19,150.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$22,090.00**	9	**$21,165.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$24,425.00**	10	**$23,180.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00

In the first year, VRC is 48% more expensive than Botball. By the 7th year, Botball gets slightly more expensive than VRC and continues past that point.

If a school already has VEX EDR parts (many do as a result of VEX EDR's use in PLTW engineering courses) and those existing parts are used, then Botball is 12% more expensive in the first year and 15% more expensive by the 10th year.

Initial Registration	GCER Registration	Field Cost	**Botball**	Year	**VEX VRC**	Initial Registration	Local Comp. Reg.	State Champ. Reg.	Worlds Reg.	Field Cost	Parts Cost
$2,500.00	$660.00	$250.00	**$3,410.00**	1	**$3,045.00**	$150.00	$240.00	$150.00	$975.00	$1,530.00	$0.00
$1,550.00	$660.00	$125.00	**$5,745.00**	2	**$5,060.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$8,080.00**	3	**$7,075.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$10,415.00**	4	**$9,090.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$12,750.00**	5	**$11,105.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$15,085.00**	6	**$13,120.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$17,420.00**	7	**$15,135.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$19,755.00**	8	**$17,150.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$22,090.00**	9	**$19,165.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00
$1,550.00	$660.00	$125.00	**$24,425.00**	10	**$21,180.00**	$150.00	$240.00	$150.00	$975.00	$500.00	$0.00



Since an overwhelming majority of VRC teams do not go to Worlds (there were 579 teams at Worlds 2019[26] with over 11000 in total[3]) and most Botball teams do not go to GCER, an analysis without highest-tier competition costs is most representative:

Initial Registration	GCER Registration	Field Cost	**Botball**	Year	**VEX VRC**	Initial Registration	Local Comp. Reg.	State Champ. Reg.	Worlds Reg.	Field Cost	Parts Cost
$2,500.00		$250.00	**$2,750.00**	1	**$4,070.00**	$150.00	$240.00	$150.00		$1,530.00	$2,000.00
$1,550.00		$125.00	**$4,425.00**	2	**$5,110.00**	$150.00	$240.00	$150.00		$500.00	$0.00
$1,550.00		$125.00	**$6,100.00**	3	**$6,150.00**	$150.00	$240.00	$150.00		$500.00	$0.00
$1,550.00		$125.00	**$7,775.00**	4	**$7,190.00**	$150.00	$240.00	$150.00		$500.00	$0.00
$1,550.00		$125.00	**$9,450.00**	5	**$8,230.00**	$150.00	$240.00	$150.00		$500.00	$0.00
$1,550.00		$125.00	**$11,125.00**	6	**$9,270.00**	$150.00	$240.00	$150.00		$500.00	$0.00
$1,550.00		$125.00	**$12,800.00**	7	**$10,310.00**	$150.00	$240.00	$150.00		$500.00	$0.00
$1,550.00		$125.00	**$14,475.00**	8	**$11,350.00**	$150.00	$240.00	$150.00		$500.00	$0.00
$1,550.00		$125.00	**$16,150.00**	9	**$12,390.00**	$150.00	$240.00	$150.00		$500.00	$0.00
$1,550.00		$125.00	**$17,825.00**	10	**$13,430.00**	$150.00	$240.00	$150.00		$500.00	$0.00

Botball is more expensive by the 4th year and significantly costlier by the 10th.

11. Conclusion

VEX VRC is a more refined program overall with significantly fewer frustrations for both students and adult sponsors while giving teams more opportunities to compete and improve their robots. It lacks the fully-autonomous focus of Botball which provides a greater challenge and fundamentally requires more critical thinking and programming; though VRC students that wish to focus on programming will not find it easy to reach a limit on how much their robots can do autonomously in the Skills Challenge. Long-term cost will generally be lower for VRC. Botball is the better option if the top priority is participating in a robotics competition with an emphasis on autonomy, or if there is not enough room for the 12’x12’ VRC field.

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Appendix A

[12][16]

Botball provides teams with a parts list in which every part has a quantity limit. It consists of:

- (5) motors and (5) servos (both in RC standard servo size)
- LEGO Technic:
    - Power transmission:
        - Wheels and tires
        - Treads
        - Gears
        - Axles
    - Structural components
- LEGO bricks
- Solarbotics wheels
- Ball caster
- Various IGUS parts
- Custom metal parts with LEGO Technic hole spacing
- An iRobot Create 2
- **Seven different types of screws (8-32, M3 structural, M3 servo horn center (low profile), M2 caster screw, unknown non-machine thread: Create, brass, servo horn)**
- Threaded rods and standoffs

Additional materials consist of:

- Letter/A4-sized sheet of 3/16” foamcore
- Letter/A4-sized sheet of 20# paper
- 100cm of 1mm max diameter thread/line/cable
- (10) #19 rubber bands
- (10) paper clips, between 1” and 1.5” in length
- Up to 250g of coins, counterweight use only
- Removable mounting dots/strips

Appendix B

[15][17]

VEX VRC allows teams to use unlimited amounts of parts from the VEX EDR catalog[8] (excluding motors and pneumatics), which includes:

- (12) 393/269 Motors *or* (8) V5 Smart Motors
- If using pneumatics:
  - (2) Pneumatic air reservoirs
  - (10) 393/269 Motors *or* (6) V5 Smart Motors
- Aluminum and steel structural components
- Threaded rods and standoffs
- Power transmission:
  - Wheels: standard, mecanum, omni
  - Gears: standard, high strength
  - Sprockets: standard, high strength
  - Chain and treads
  - Axles (shafts): standard, high strength
  - Bearings
  - Idler pulleys
- **Three different types of screws (8-32, 6-32, 8-32 set screw)**
- Foam with adhesive backing
- Anti-slip mats
- #32 and #64 rubber bands

Additional materials consist of (copied from the VRC Turning Point Game Manual[8]):

- a. Any material strictly used as a color filter or a color marker for a VEX Light Sensor.
- b. Any parts which are identical to legal VEX parts. For the purposes of this rule, products which are identical in all ways except for color are permissible. It is up to inspectors to determine whether a component is "identical" to an official VEX component.

- c. Any commercially available #4, #6, #8, M2, M2.5, M3 or M4 screw up to 2" long (nominal), and any commercially available nut and/or washer to fit these screws. The intent of the rule is to allow teams to purchase their own commodity hardware without introducing additional functionality not found in standard VEX equipment. It is up to inspectors to determine whether the non-VEX hardware has introduced additional functionality or not.
- d. Any non-aerosol based grease or lubricating compound, when used in extreme moderation on surfaces and locations that do NOT contact the playing field walls, foam field surface, game objects, or other robots.
- e. Non-shattering plastic from the following list; polycarbonate (Lexan), acetel monopolymer (Delrin), acetal copolymer (Acetron GP), POM (acetal), ABS, PEEK, PET, HDPE, LDPE, Nylon (all grades), Polypropylene, FEP; as cut from a single 12" x 24" sheet up to 0.070" thick.
- i. Shattering plastic, such as acrylic, is prohibited.
- ii. Plastic may be mechanically altered by cutting, drilling, bending etc. It cannot be chemically treated, melted or cast. Heating polycarbonate to aid in bending is acceptable.
- f. A small amount of tape may be used for the following purposes:
    - i. For the sole purpose of securing any connection between the ends of two (2) VEX cables.
    - ii. For labeling wires and motors.
    - iii. For the purposes of preventing leaks on the threaded portions of pneumatic fittings. This is the only acceptable use of Teflon tape.
    - iv. For securing and retaining a VEXnet Key 2.0 to the VEX ARM® Cortex®-based Microcontroller. Using tape in this manner is highly recommended to ensure a robust connection.
    - v. All other functional uses of tape, such as grip tape or duct tape, are prohibited.
- g. Hot glue for securing cable connections.
- h. A USB extension cable may be used for the sole purpose of remote mounting of a VEXnet Key 2.0 to a VEX ARM® Cortex®-based Microcontroller

- i. An unlimited amount of 1/8” (or local metric equivalent), braided, nylon rope
- j. Commercially available items used solely for bundling or wrapping of 2-wire, 3-wire, 4-wire, or V5 Smart Cables, and pneumatic tubing are allowed. These items must solely be used for the purposes of cable protection, organization, or management. This includes but is not limited to electrical tape, cable carrier, cable track, etc. It is up to inspectors to determine whether a component is serving a function beyond protecting and managing cables.
- k. VEX IQ pins used solely for the purpose of attaching VEX Team Identification Number Plates.